Status of MICE

NUFACT09
Illinois Institute of Technology
Chicago, 21 July 2009
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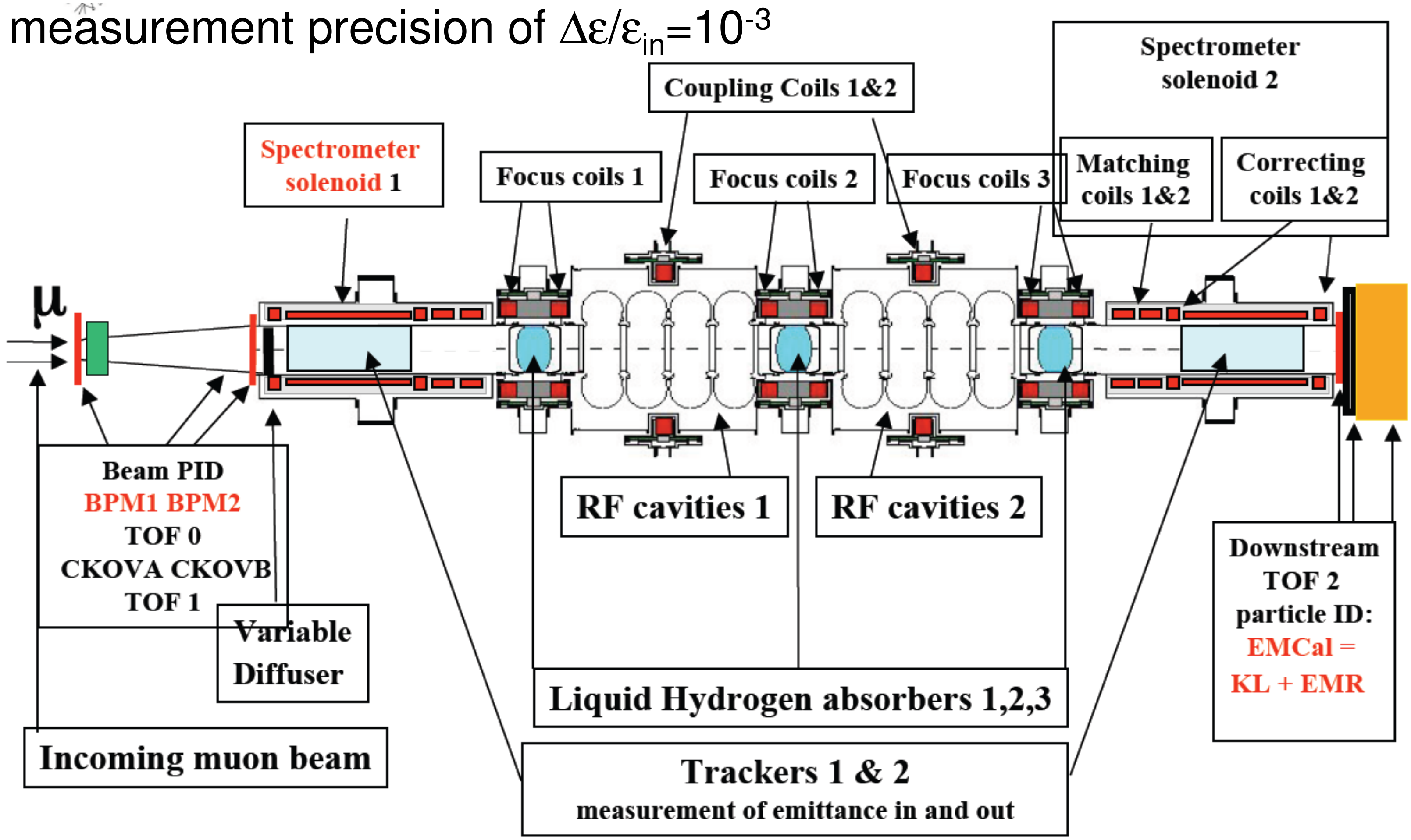
(*on behalf of the MICE Collaboration)

Contents

Note that there are also a number of posters on MICE at the NUFACT09 poster session

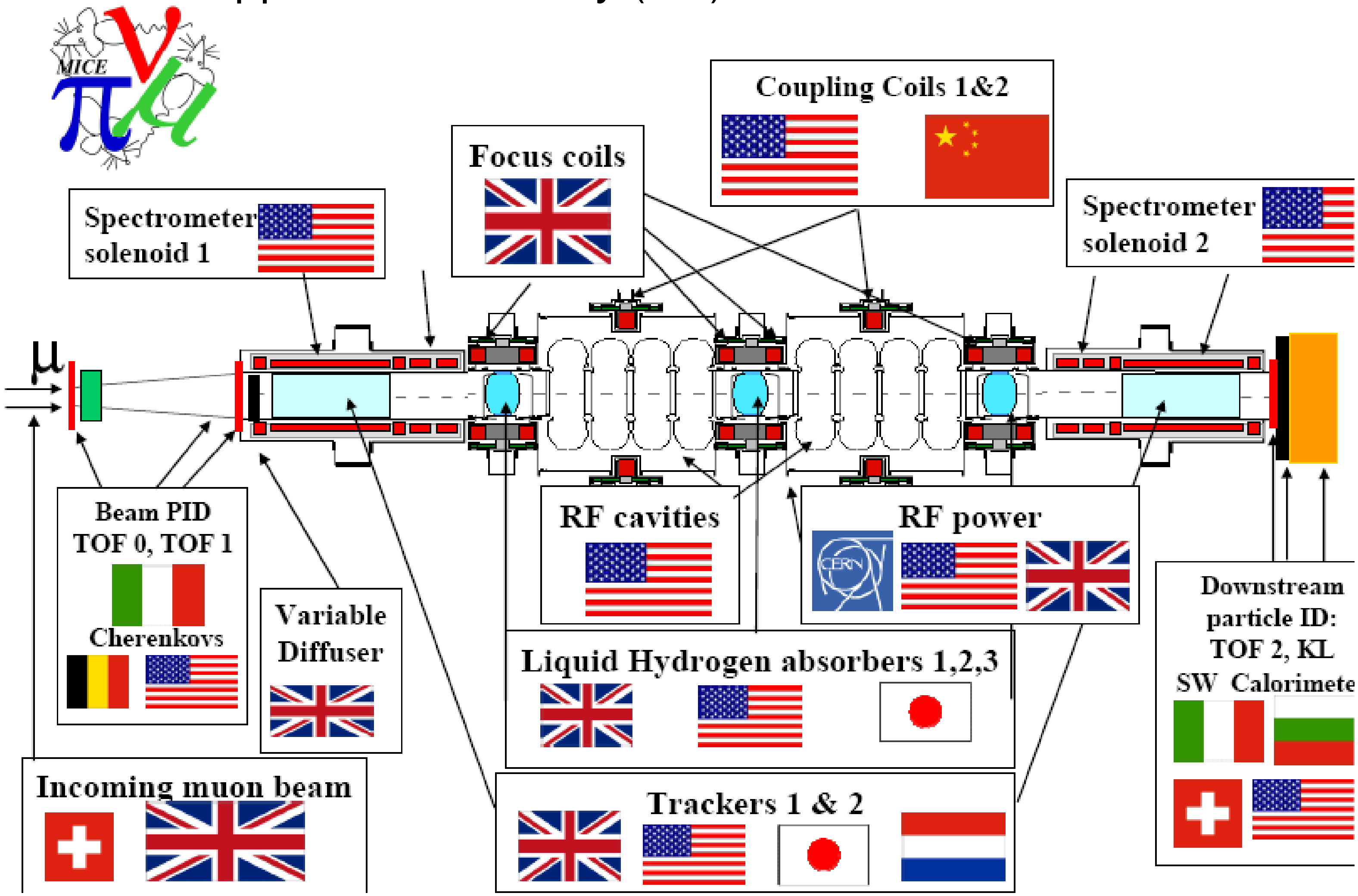
MICE aims

- The Muon Ionization Cooling Experiment (MICE) is being built at the Rutherford Appleton Laboratory (RAL) to measure ionization cooling from a beam of muons traversing liquid hydrogen and other low Z absorbers (LiH).
- The aim of MICE is to measure ~10% cooling of 140-240 MeV/c muons with a measurement precision of $\Delta\varepsilon/\varepsilon_{in}=10^{-3}$



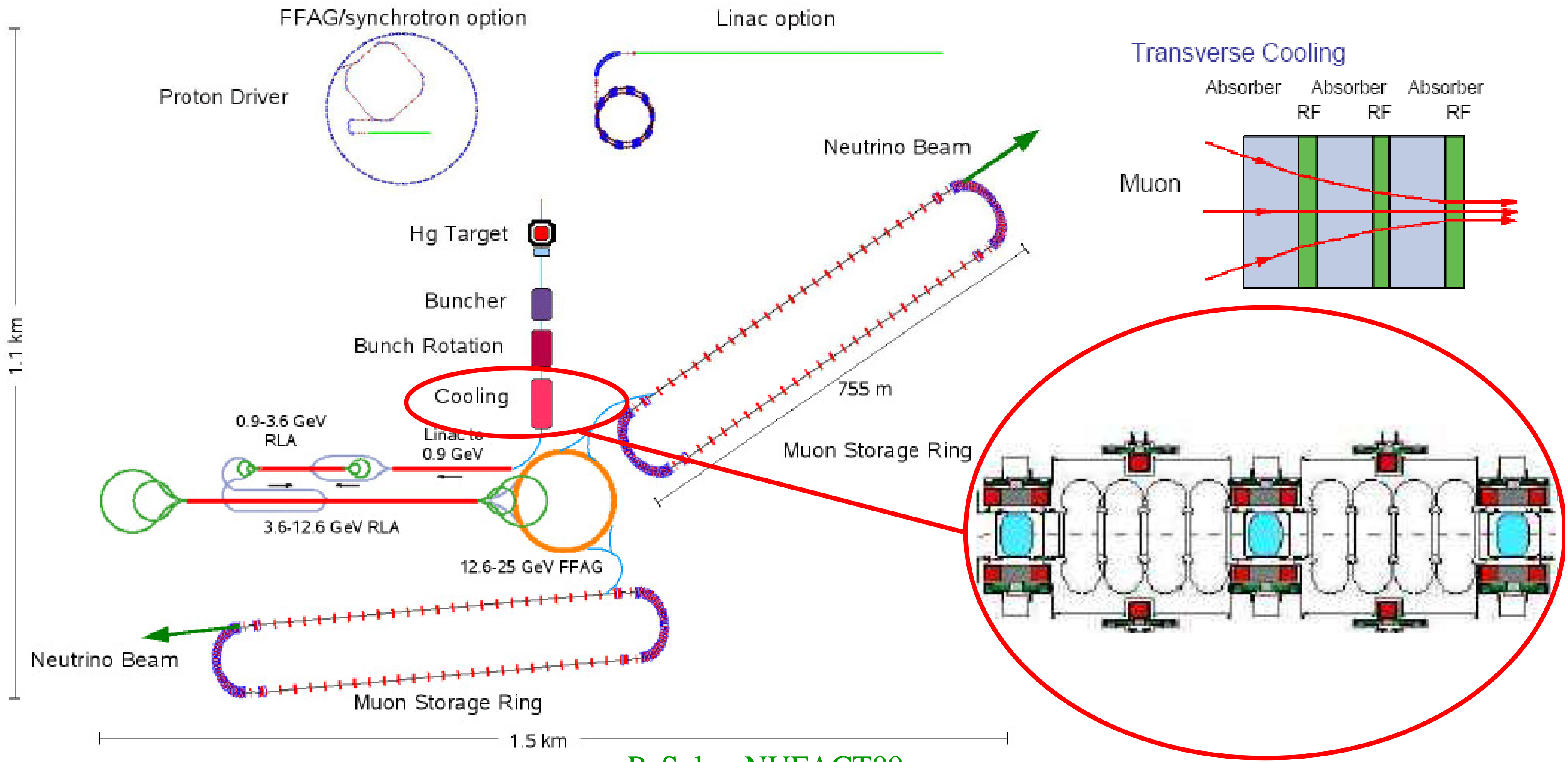
MICE Collaboration

- International Muon Ionization Cooling Experiment (MICE): Belgium, Bulgaria, China, Holland, Italy, Japan, Switzerland, UK, USA based at Rutherford Appleton Laboratory (UK): ~150 collaborators



Neutrino Factory

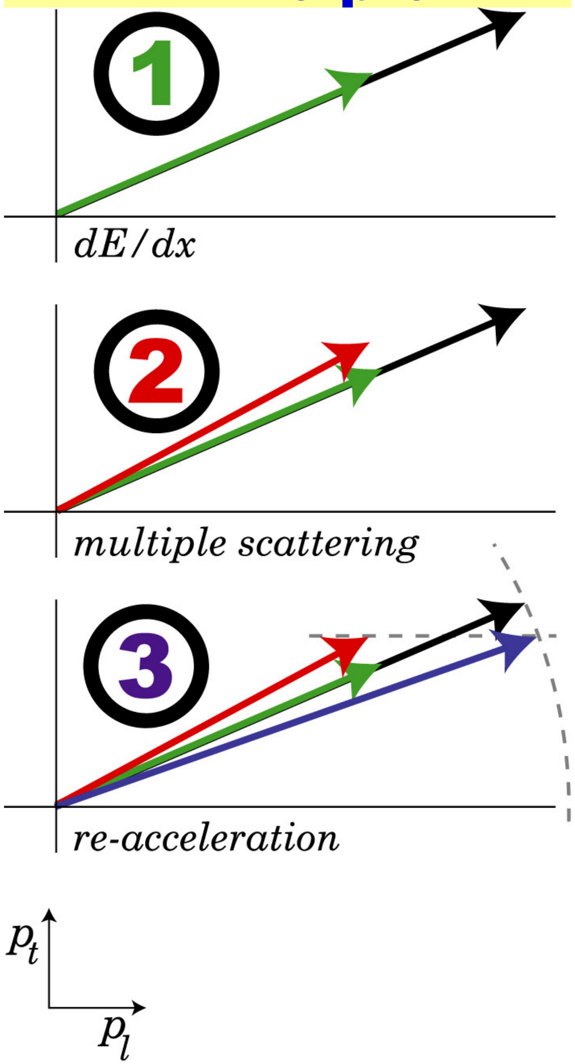
- Baseline design for a Neutrino Factory from International Design Study
- Design includes a Muon Ionization Cooling stage



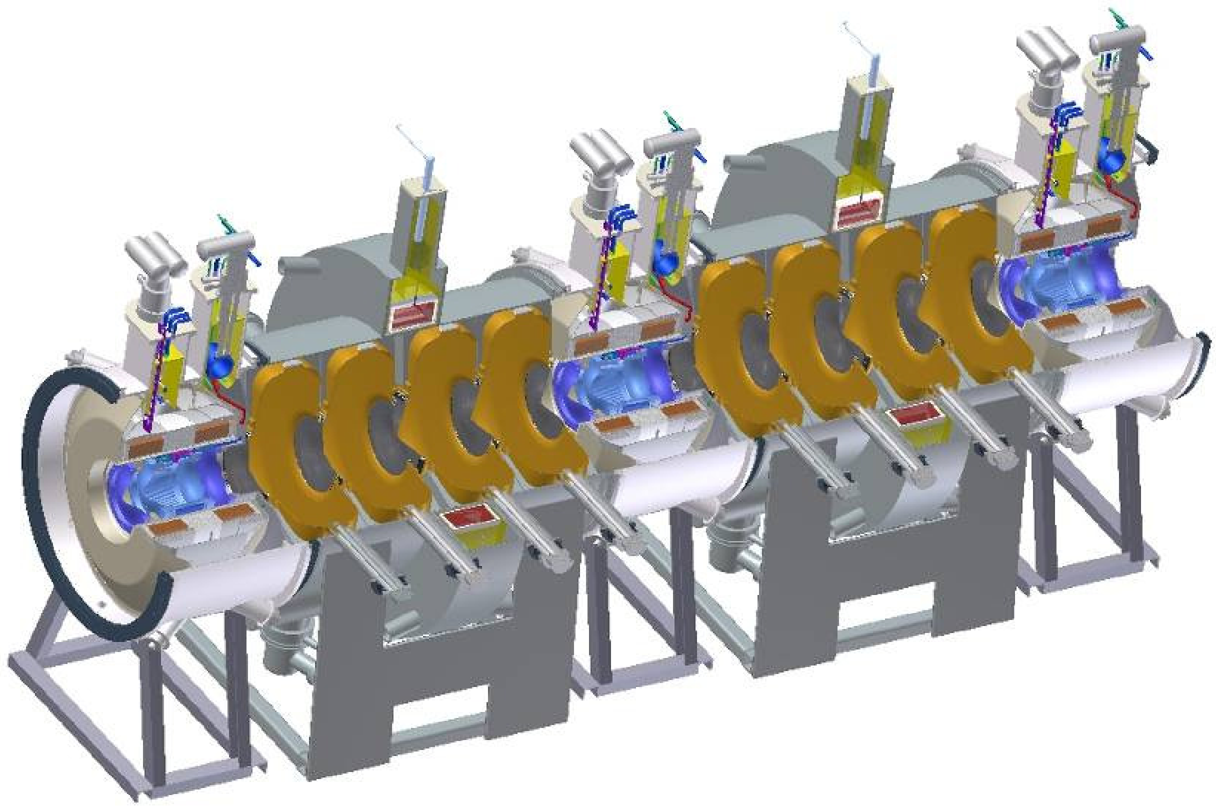
Ionization Cooling

Needed to achieve 10^{21} μ/yr

Principle



Practice



~ 20% cost of neutrino factory

Ionization Cooling

- Ionization cooling:
  - Ionization gives cooling term, multiple scattering gives a heating term

$$\frac{d\varepsilon}{dz} \approx -\frac{\varepsilon}{E_\mu \beta^2}\frac{dE_\mu}{dz} + \frac{\beta_\perp}{2m\beta^3}\frac{(13.6\,MeV)^2}{E_\mu X_0}$$

  - Ionization per density is proportional to Z, multiple scattering is inversely proportional to X_0 thus prop to Z(Z+1)
  - Thus, best cooling achieved with low Z: hydrogen, lithium hydride (LiH)
- Definition of emittance:

Need to perform single particle experiment to measure ε with full correlations

  - V_{ij} is covariance matrix of phase space:

$$V_{ij} = \begin{bmatrix} \beta_\perp / p_z & -\alpha_\perp & 0 & -(\beta_\perp\kappa - \mathcal{L}) \\ -\alpha_\perp & p_z\gamma_\perp & +(\beta_\perp\kappa - \mathcal{L}) & 0 \\ 0 & +(\beta_\perp\kappa - \mathcal{L}) & \beta_\perp / p_z & -\alpha_\perp \\ -(\beta_\perp\kappa - \mathcal{L}) & 0 & -\alpha_\perp & p_z\gamma_\perp \end{bmatrix}$$

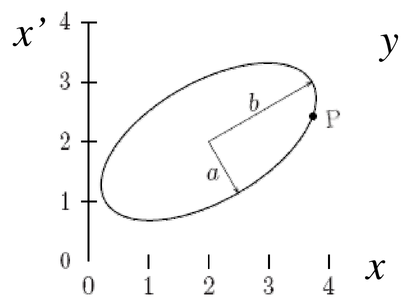
$\alpha_\perp, \beta_\perp, \gamma_\perp$ = Twiss parameters

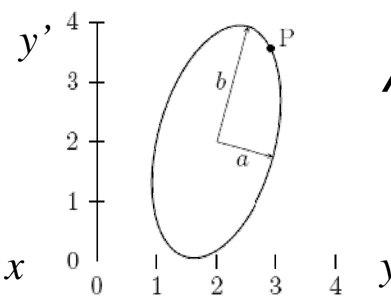
$$\mathcal{L} \approx \frac{\langle L_{canon} \rangle}{2m_\mu c\varepsilon_N}$$

κ = radius of curvature

Emittance: area of 4D ellipse
($x, x' \equiv p_x/p_z$, $y, y' \equiv p_y/p_z$)

$$\varepsilon_{4D} = \frac{1}{m_\mu c}\sqrt[4]{|V_{ij}|}$$



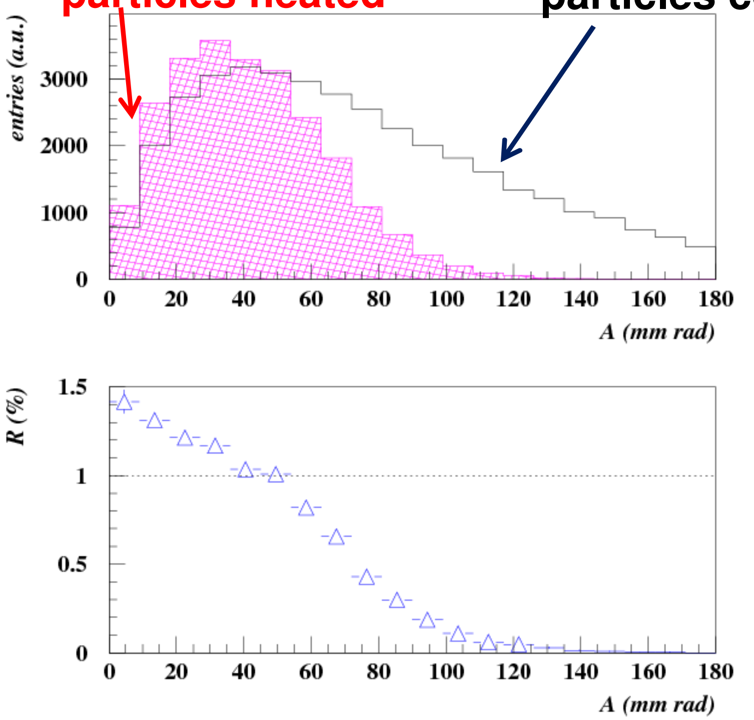


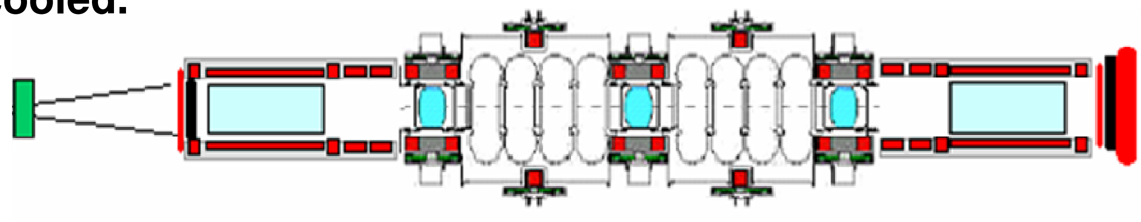
$$A = \pi\sqrt{|V|}$$

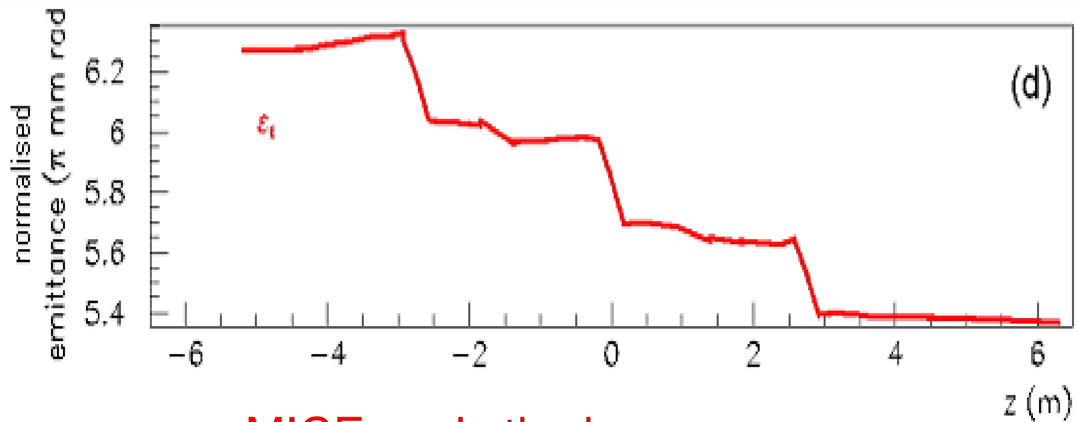
Expected MICE Performance

Low amplitude particles heated

High amplitude particles cooled.







MICE cools the beam on average

Change in emittance at absorber: $\Delta\varepsilon / \varepsilon = -(\Delta p/p)(1-\varepsilon_0/\varepsilon)$

5% momentum loss in each absorber ➔ 15% cooling for large ε beam

Equilibrium emittance for H_2 $\varepsilon_0 \sim 2.5$ (π) mm-radians

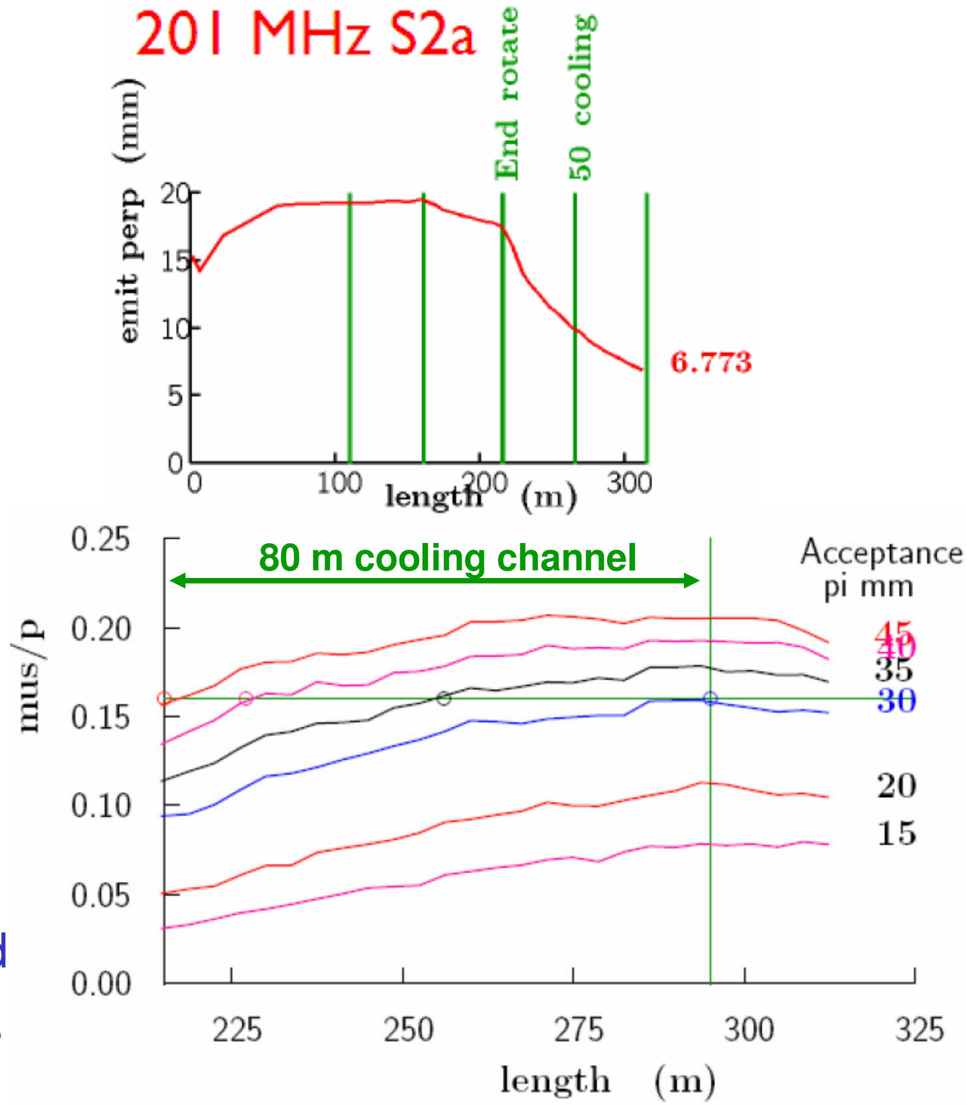
(acceptance of accelerators in NuFact 15 – 30 (π) mm-radians)

➔ Measure Δε to 1% , implies measurement ε to 0.1%

Cooling needs Neutrino Factory

Performance of cooling channel: Neutrino Factory Study 2a (USA) (acceptance 30π mm rad)

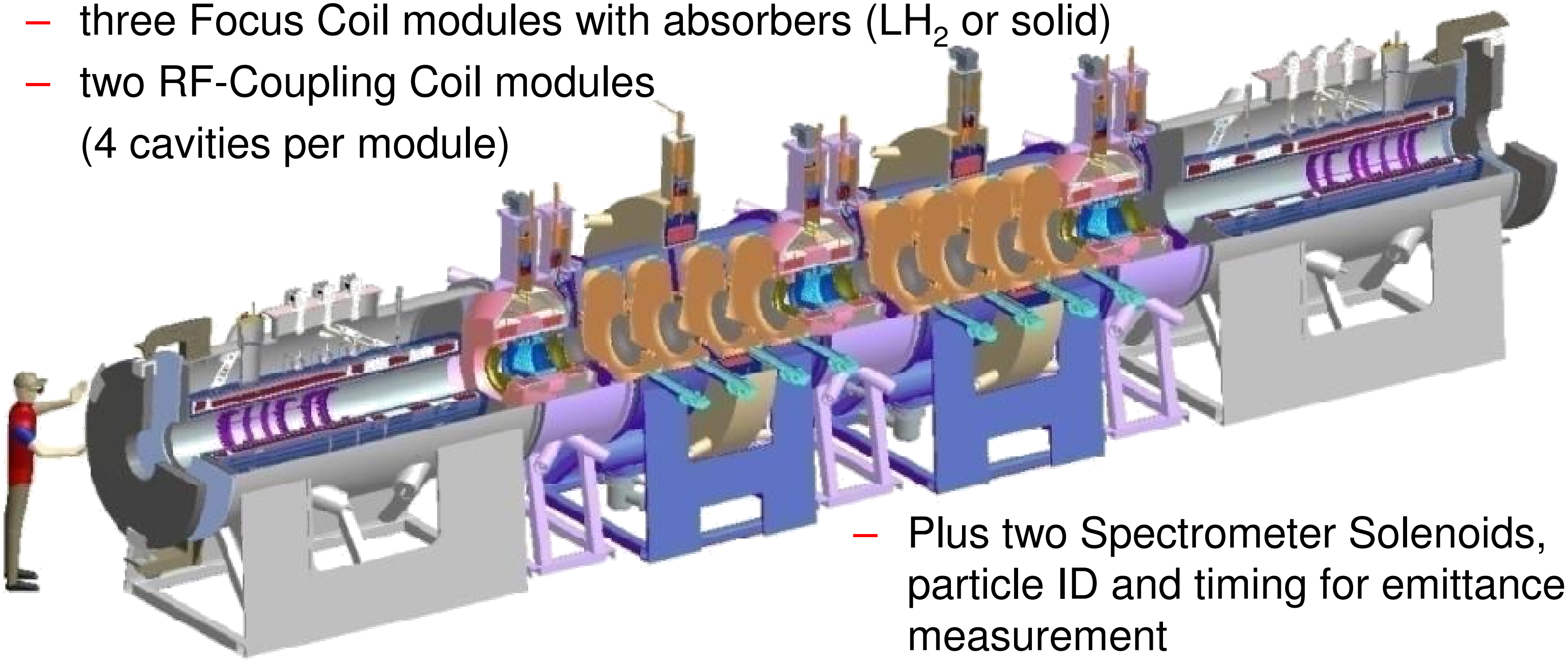
Only NuFact Sudy 2a (S2a) with both signs meets goal of 10^{21} μ decays/year given 0.17 μ/p



- Trade-off cooling efficiency vs. downstream acceptance
  - Increasing from 30 to 35 π mm-rad halves required length cooling channel
  - At 45 π mm-rad, no cooling needed
- Even achieving A = 30 π mm-rad is difficult

MICE

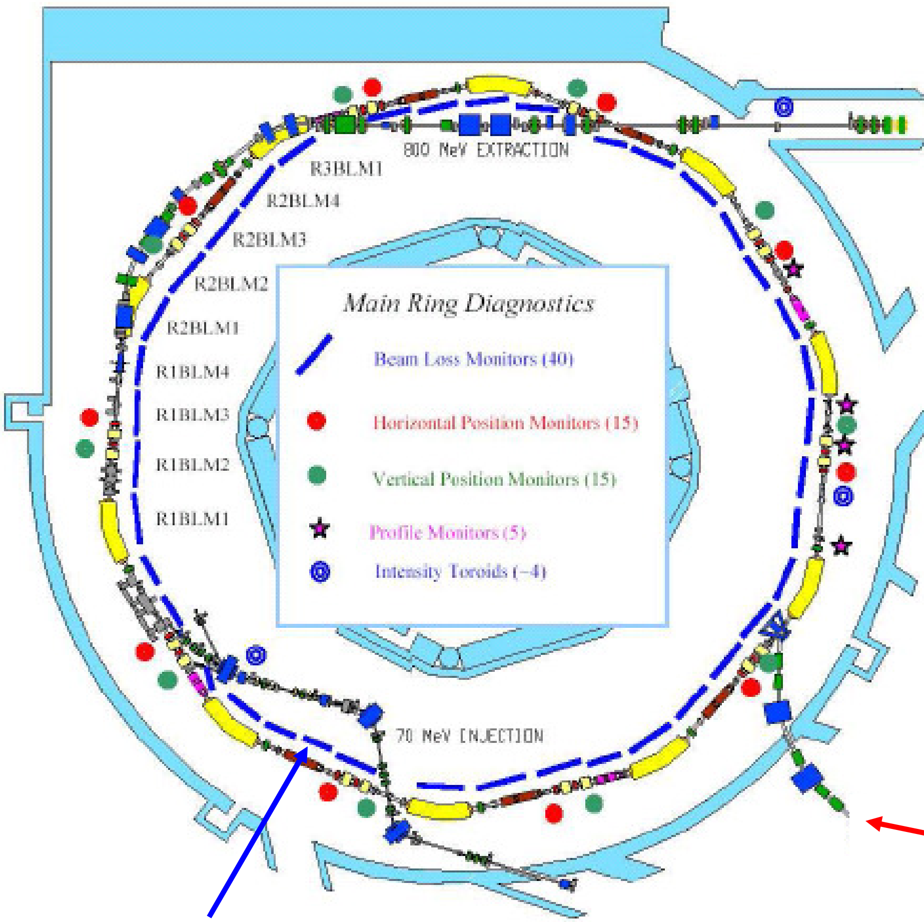
- Cooling demonstration aims to:
  - design, engineer, and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory
  - place this apparatus in a muon beam and measure its performance in a variety of modes of operation and beam conditions
  - show that design tools (simulation codes) agree with experiment
- MICE includes one cell of the FS2 cooling channel:
  - three Focus Coil modules with absorbers (LH_2 or solid)
  - two RF-Coupling Coil modules (4 cavities per module)



  - Plus two Spectrometer Solenoids, particle ID and timing for emittance measurement

ISIS Synchrotron

- The MICE muon beamline will be extracted from the ISIS synchrotron at RAL



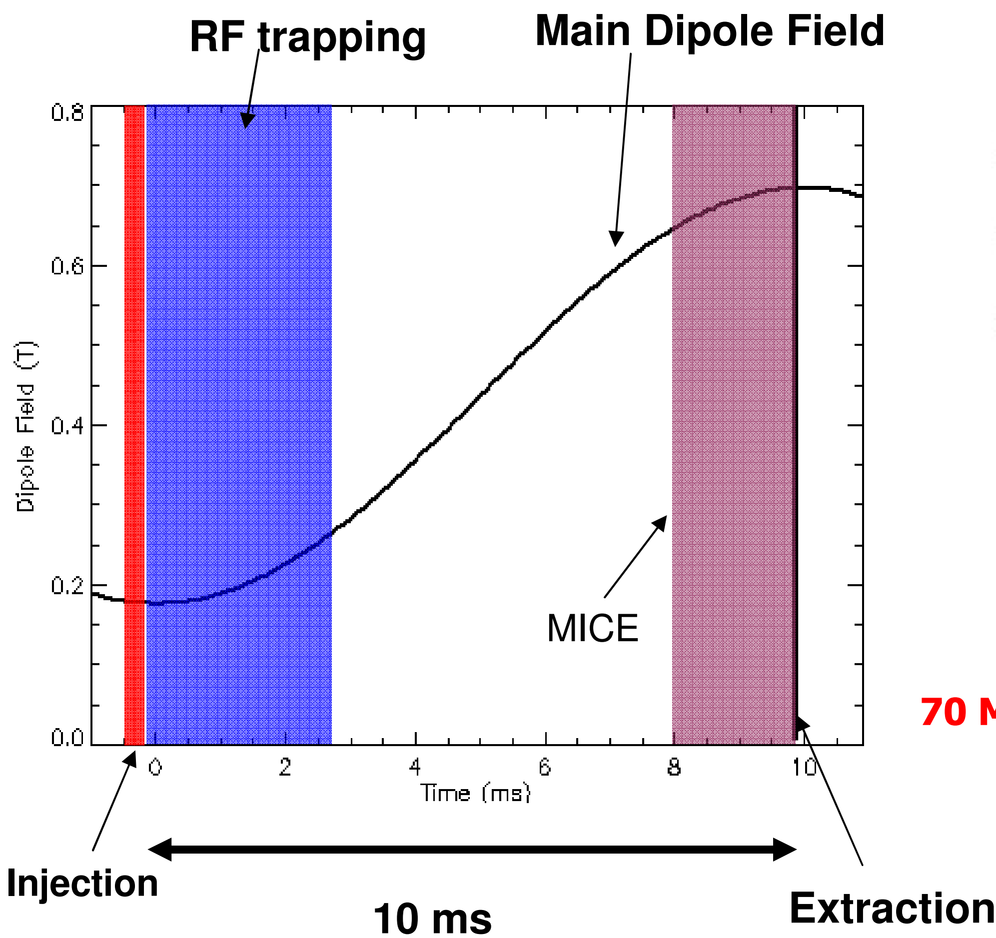
MICE Beamline

Beam loss monitors

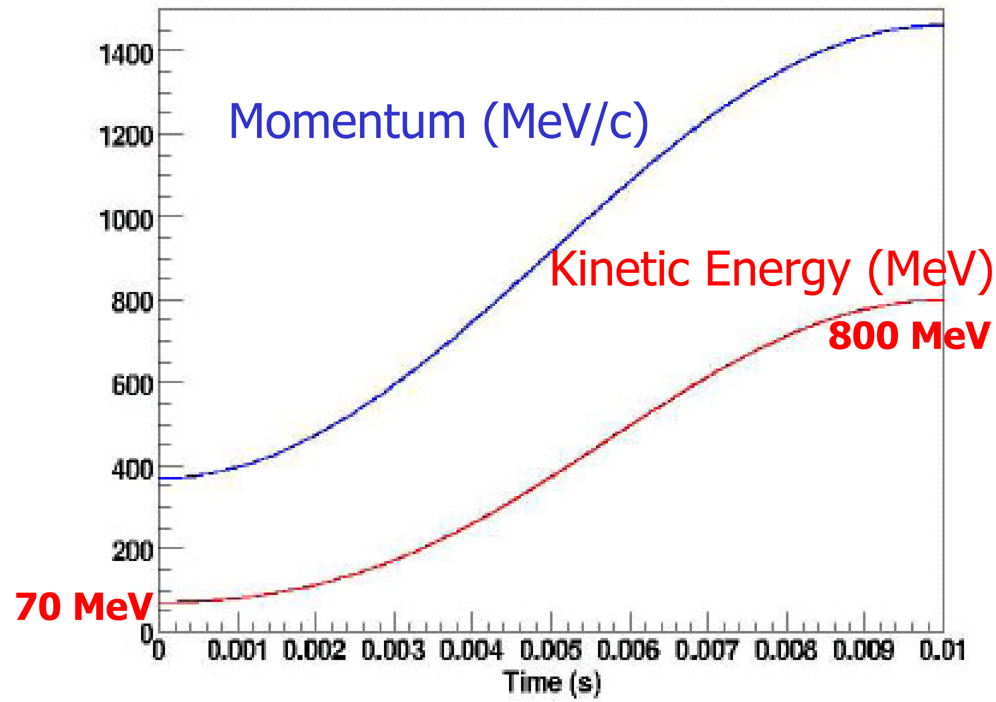
- Protons injected with KE=70 MeV
- Acceleration up to KE=800 MeV
- Acceleration time = 10 ms
- Machine frequency = 50 Hz.
- Bunch rep. rate = 1.5×10^6 Hz
- 10 dipole magnets (R=7 m)
- Ring radius = 26 m
- Peak acceleration by 6 RF cavities: 140 kV per turn

ISIS Synchrotron

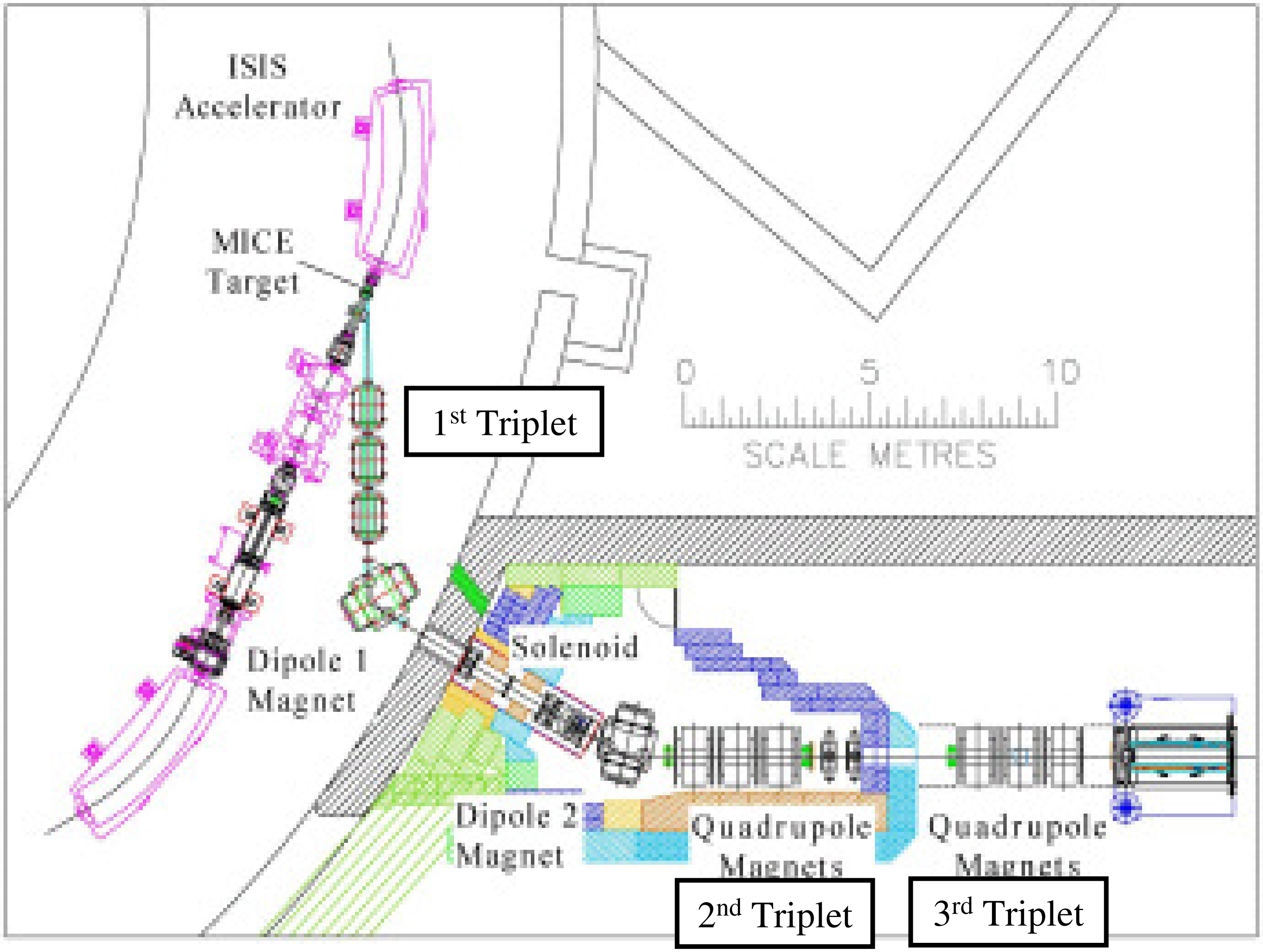
- Acceleration cycle of the ISIS protons:



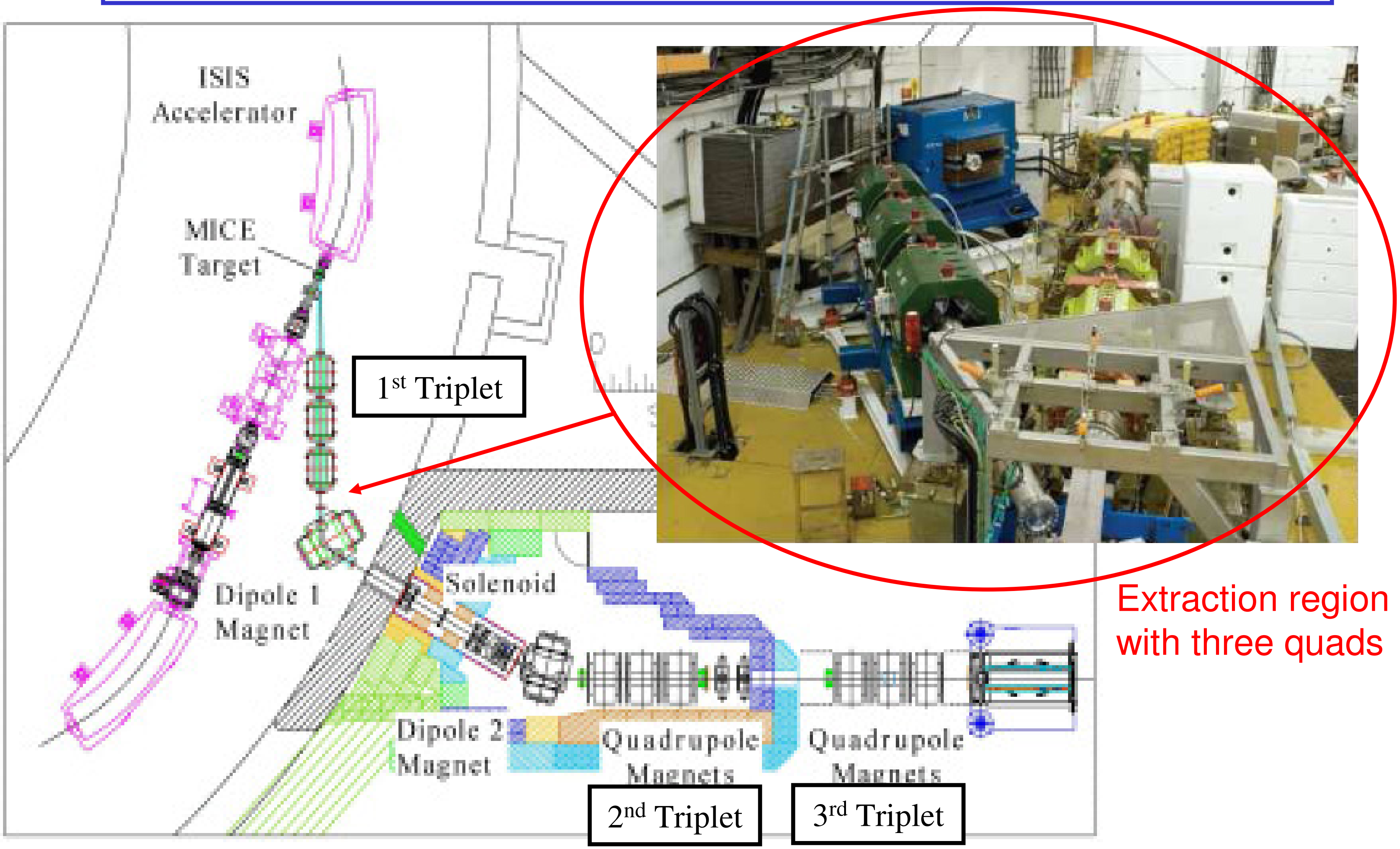
Proton momentum and KE of ISIS accelerator



MICE Beamline

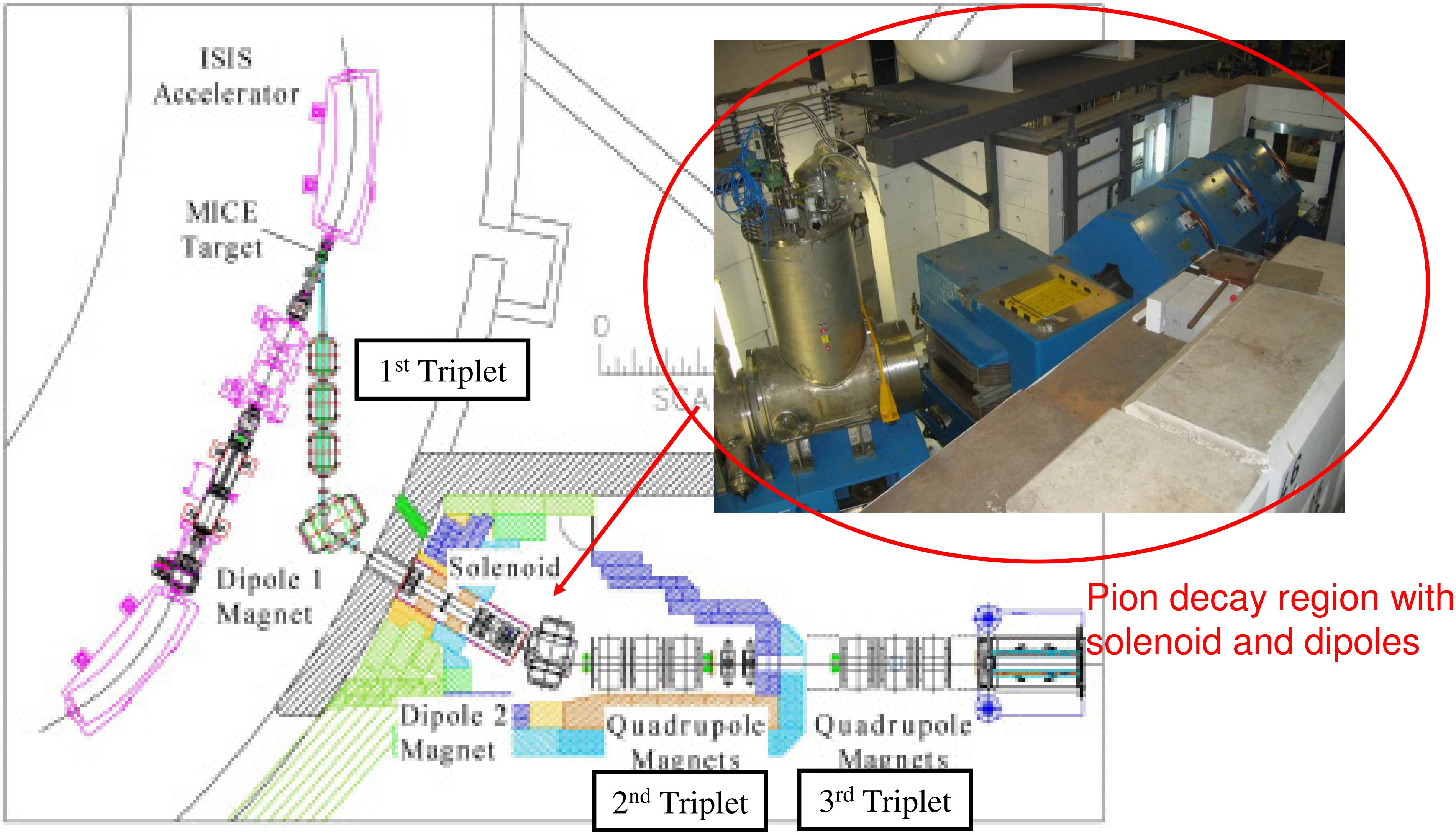


MICE Beamline

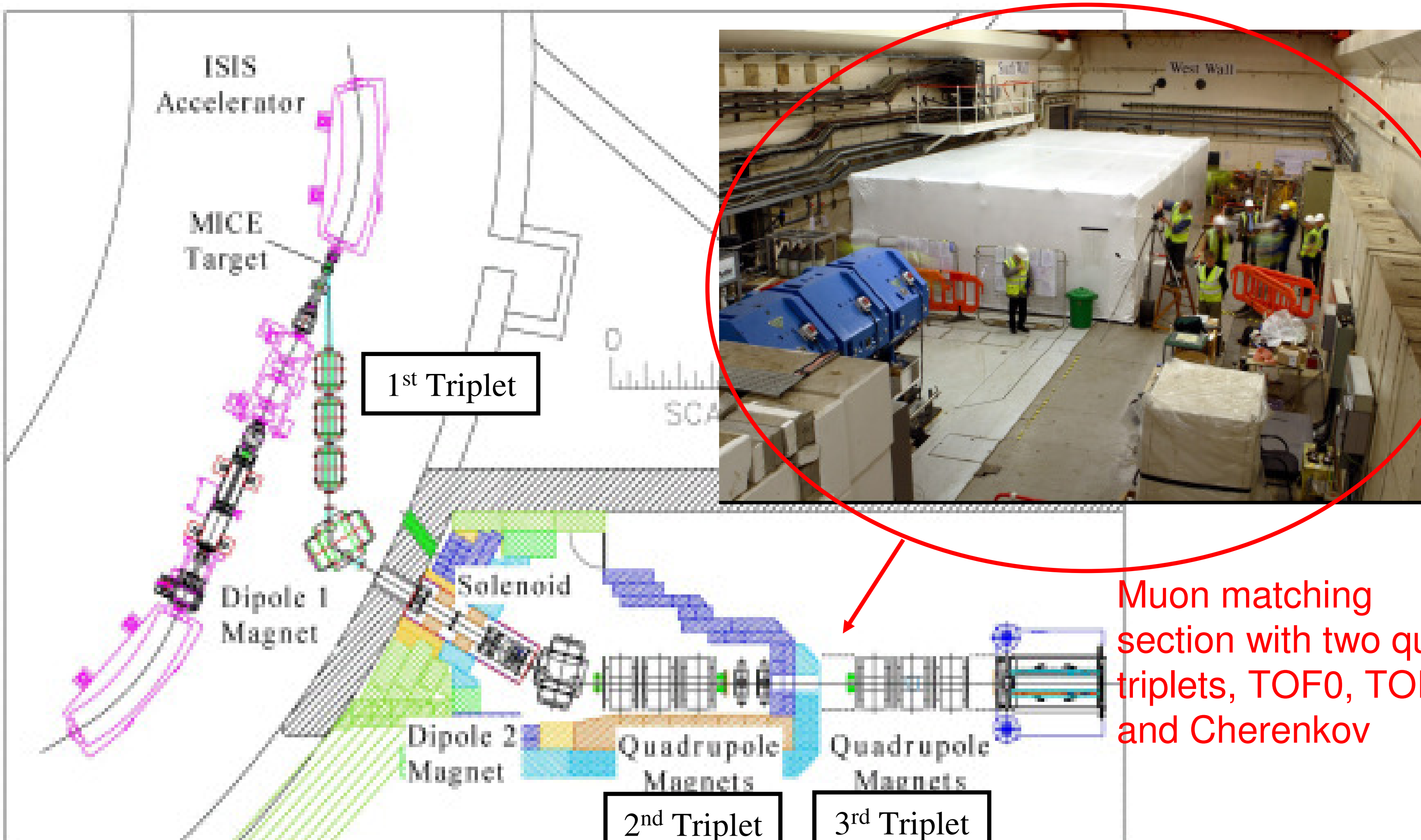


Extraction region
with three quads

MICE Beamline



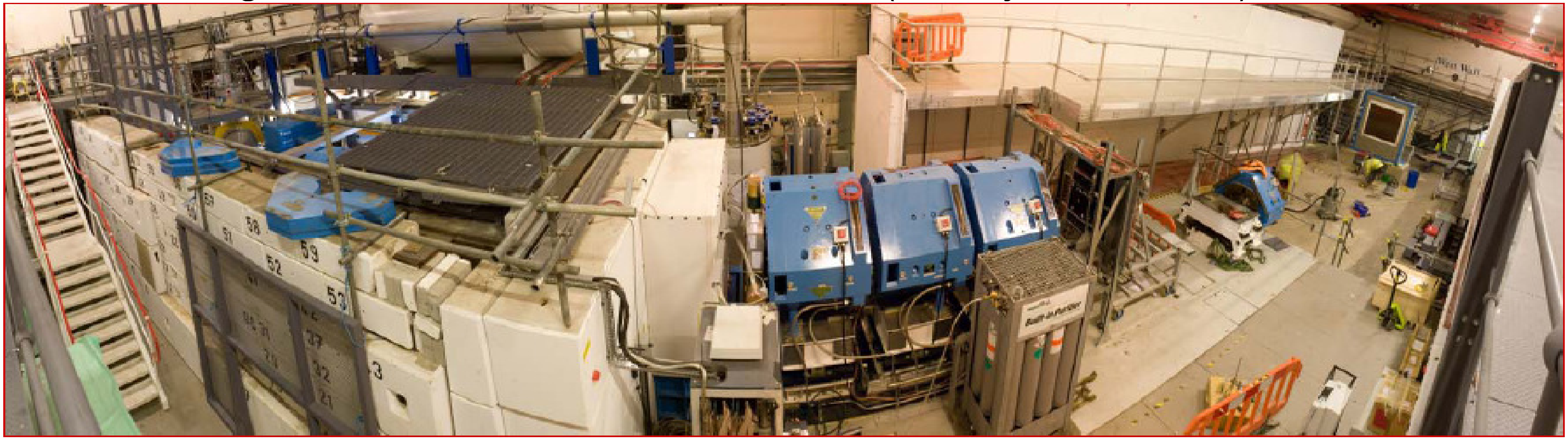
MICE Beamline



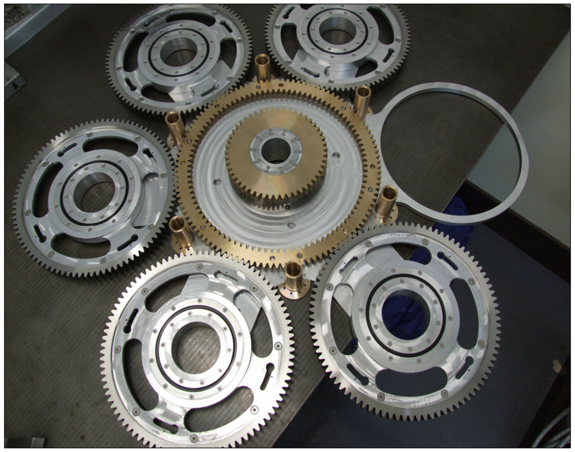
Muon matching section with two quad triplets, TOF0, TOF1 and Cherenkov

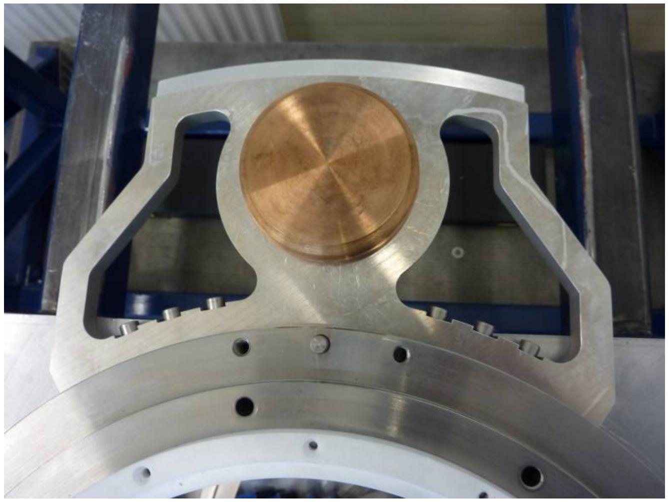
MICE Beamline

- All magnets in MICE beamline installed (fish-eye lens view):



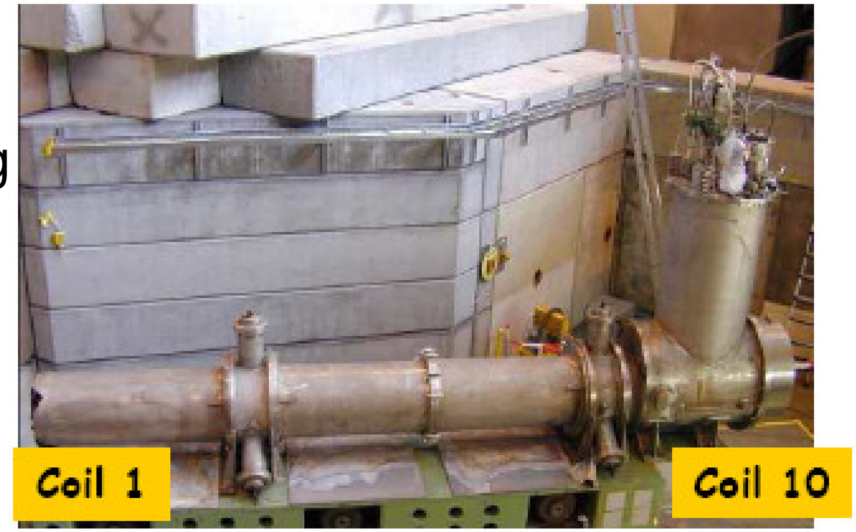
- Diffuser: rotating wheel with different thicknesses of material to blow up beam for large emittance beams
  - To be ready Sept 09

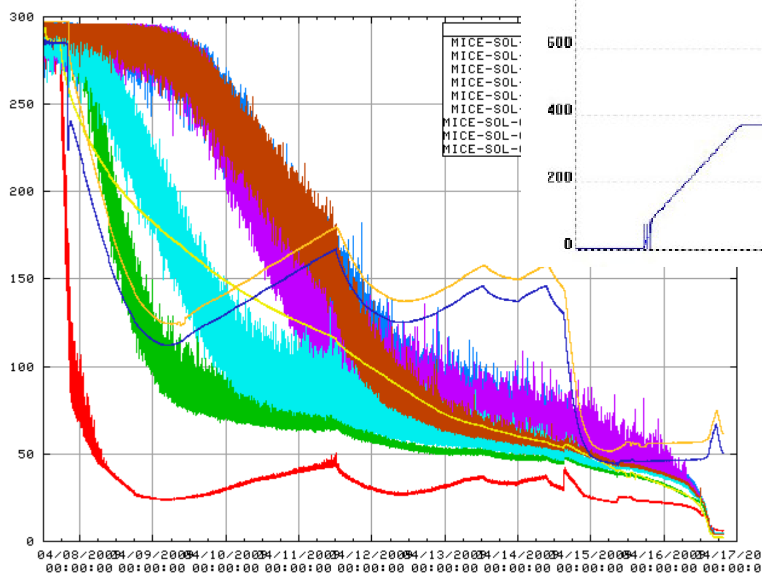




MICE Beamline

- Decay solenoid repaired:
  - Coil 10 could not go superconducting
  - Multi-layer insulation (MLI) installed
  - Cool down to 4.5K (Apr 09)
  - Magnet powered up to 5T (Apr 09)

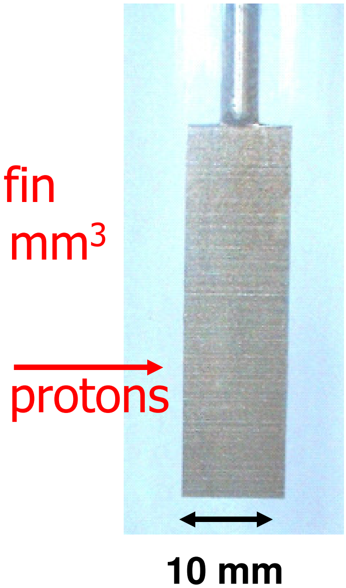




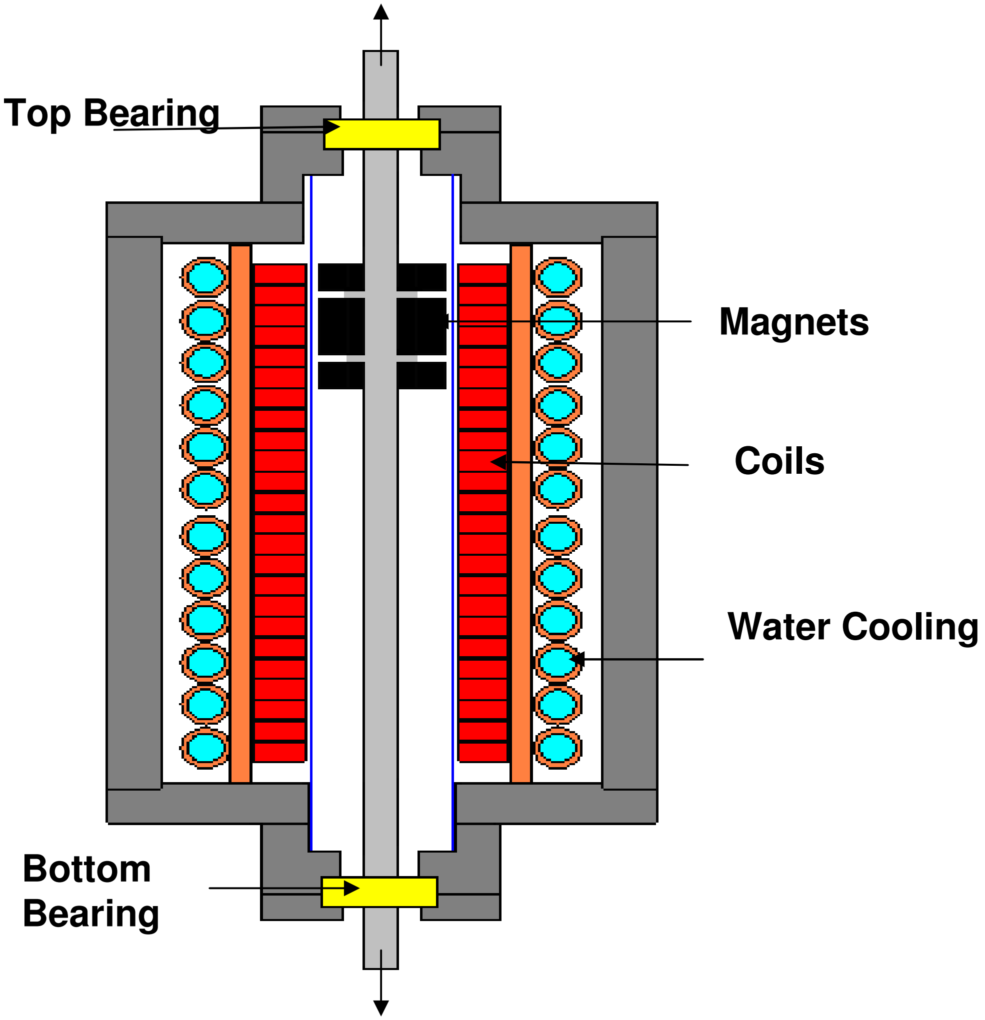
MICE Target

- Target and target mechanism design for 2008 run
- Target: titanium fin 10x10x1 mm^3
- Target insertion mechanism:
  - Linear motor with radial magnet
  - Remote position sensing with laser quadrature readout
  - Drives commutator power to correct 24 coil currents

Target:
titanium fin
10x10x1 mm^3

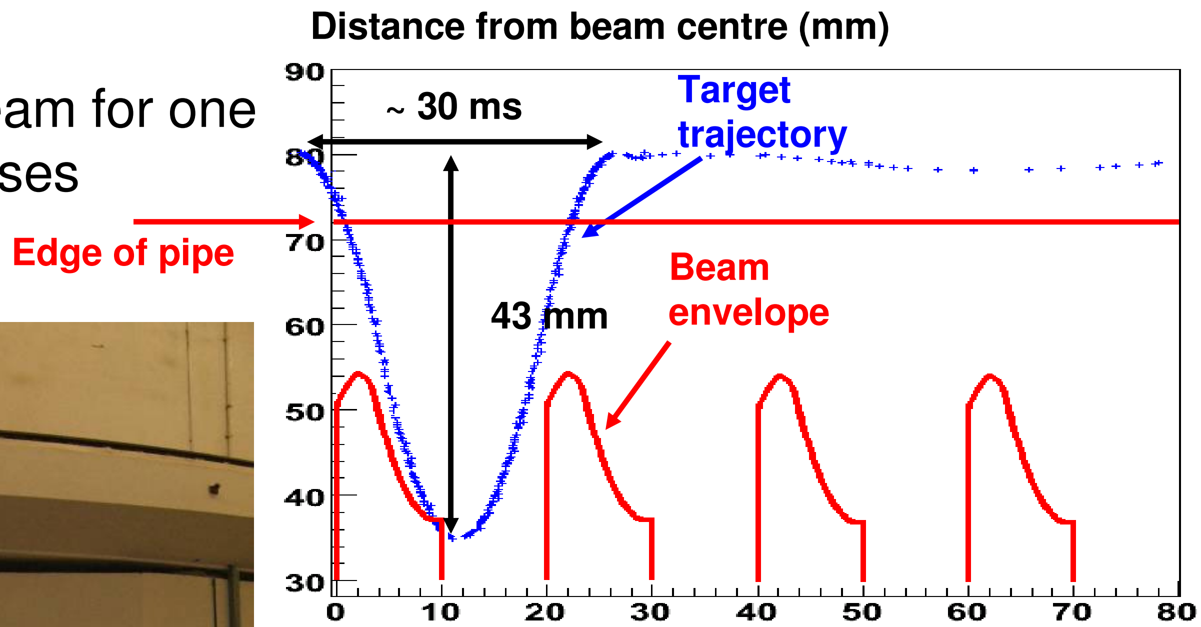


Schematic of target insertion mechanism



MICE Target

- Target cycles at ~1 Hz
- Target only dips into beam for one pulse every 50 ISIS pulses



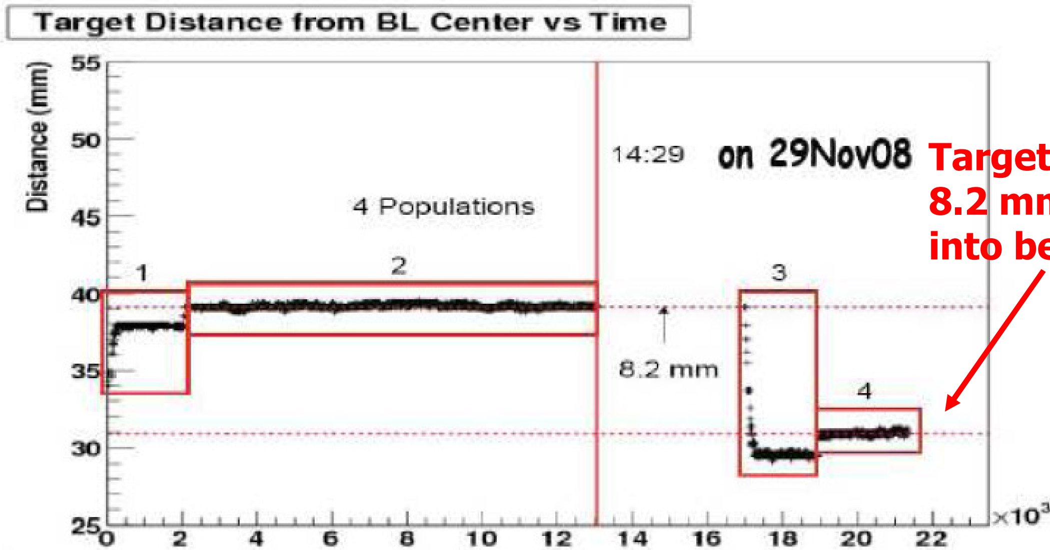
Target installed at RAL

Intersection of target with beam during last millisecond of acceleration cycle (ie. 9-10 ms after injection) for protons with KE ~ 800 MeV

Acceleration requirement: ~80g

MICE Target

- Target operated successfully March-December 2008
- Target was accidentally "parked" in beam on 29 Nov 2008: target tip melted
- Target mechanism got jammed in December 2008



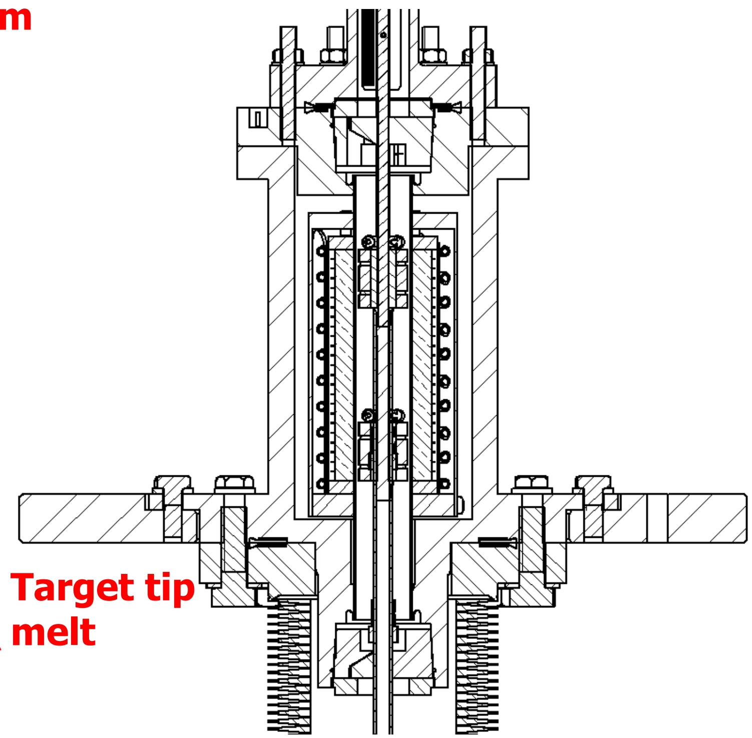
Target inserted 8.2 mm further into beam

Opportunity to redesign target mechanism and new cylindrical target shaft

New working target to be installed ISIS shutdown
17 Aug-2 Sep 2009

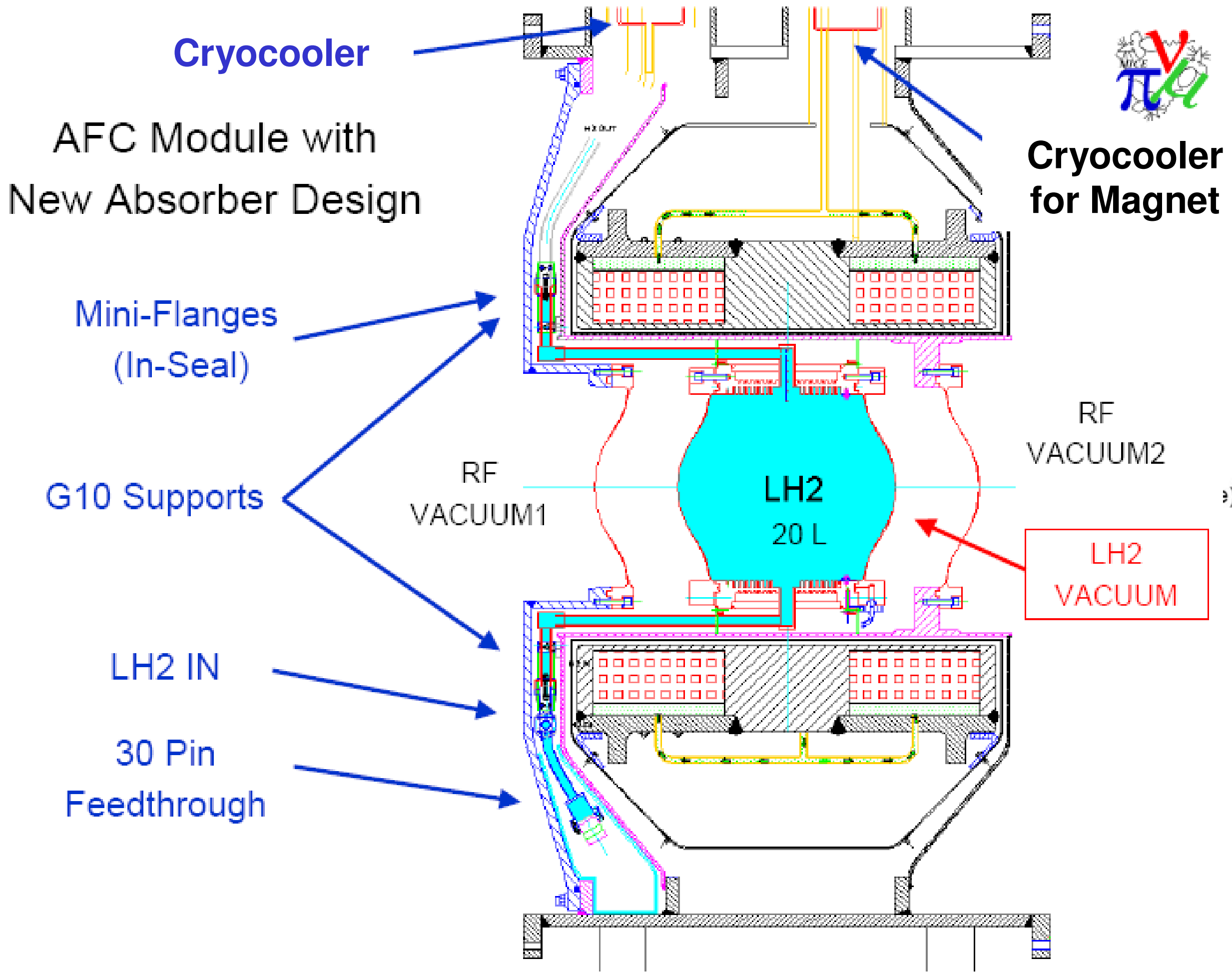
Tight schedule!

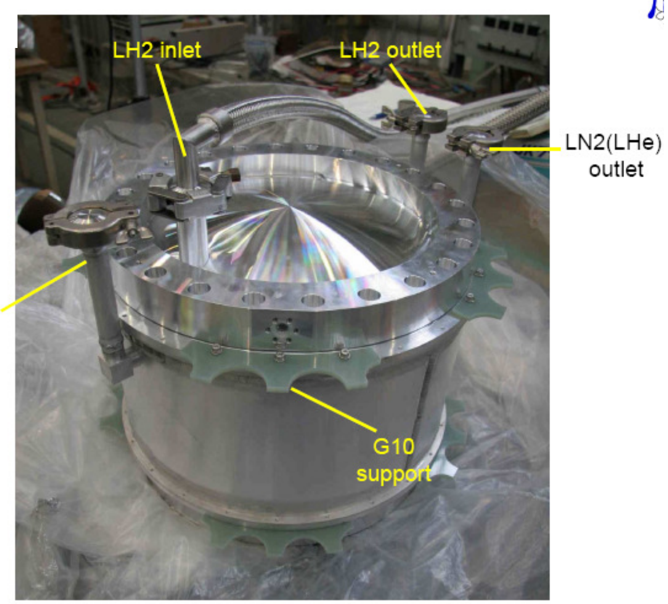
Target tip melt



MICE Absorbers

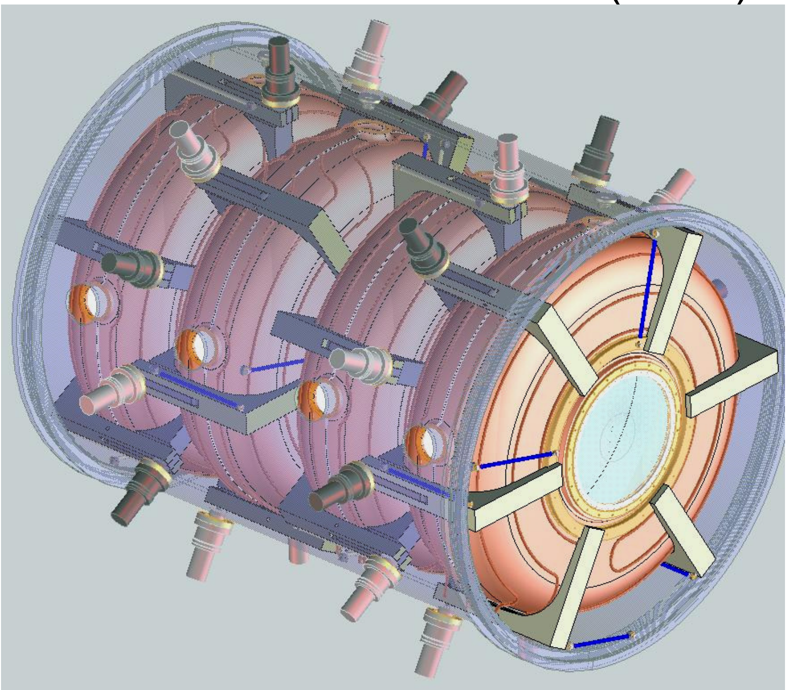
- Liquid hydrogen absorber with focus coil magnets:

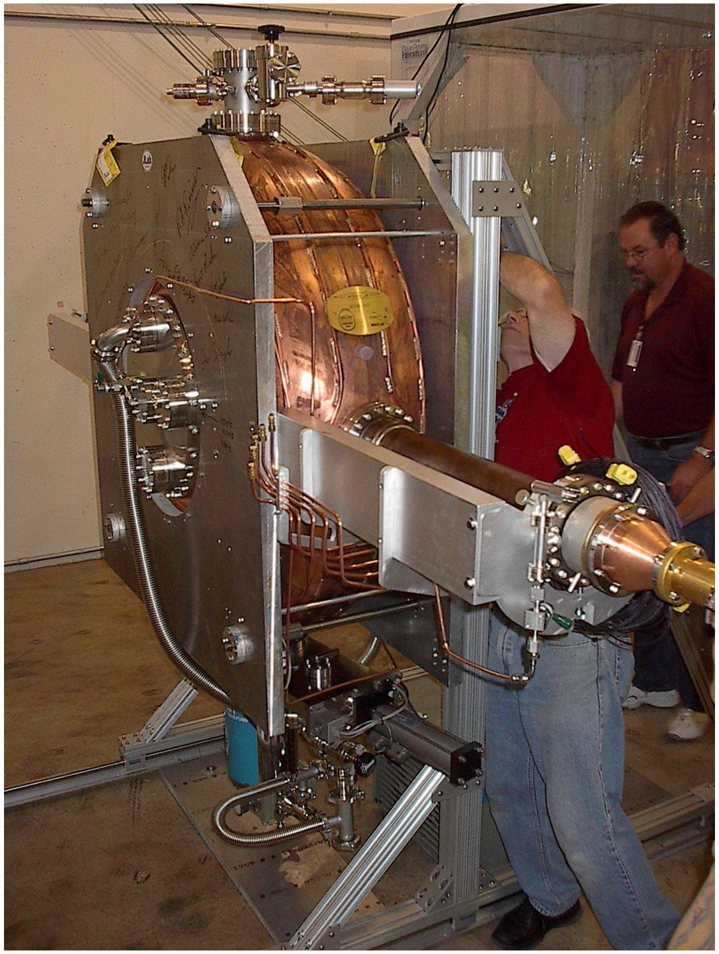




RF cavities

- Four 201.25 MHz copper-niobium cavities per RFCC module
- Cavities in manufacture
- Production Readiness Review (PRR) 29 July at LBNL

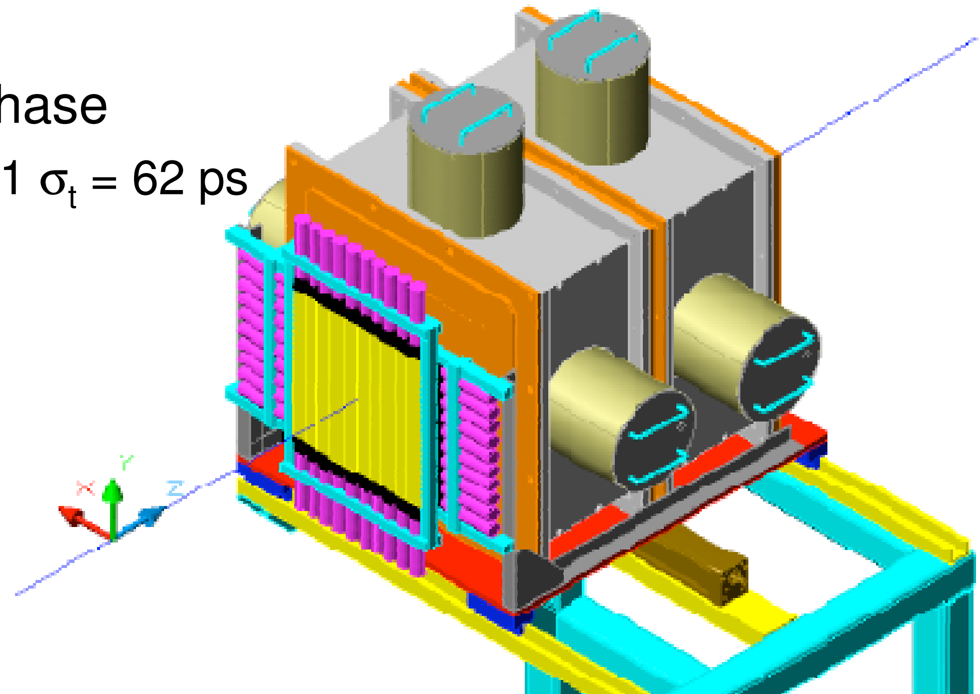


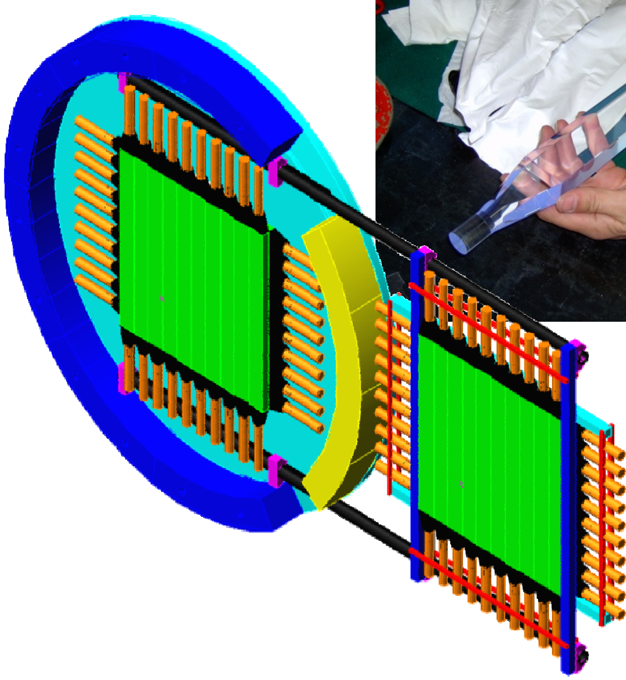


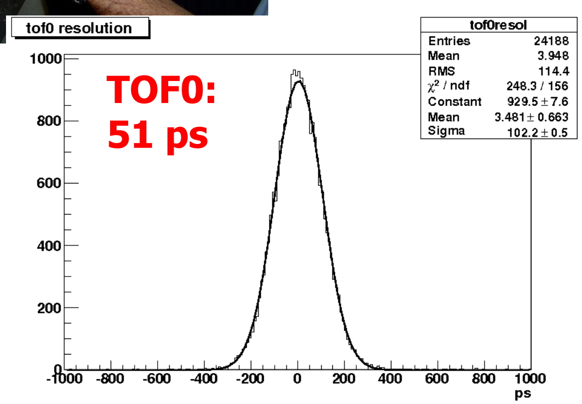
Specs: β = 0.87, Q_0 ~ 53,500
Be window radius: 21cm; thickness 0.38 mm
Peak input RF power ~ 4.6 MW per cavity
Gradient: ~ 16 MV/m

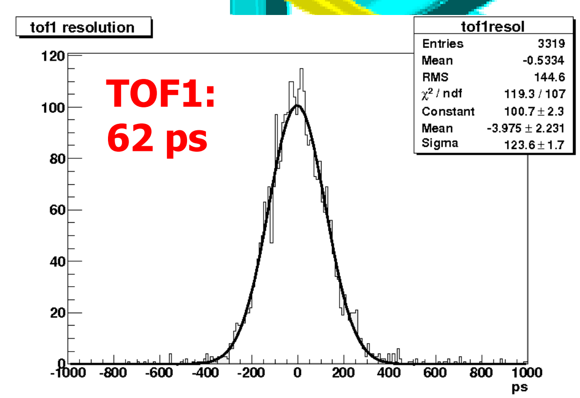
MICE Detector systems

- Cherenkov detector:
  - Two aerogels with different refractive index, read out by 4 PMTs
  - Pion-muon separation
- Time of Flight (TOF): PID and RF phase
  - Three TOFs: TOF0 σ_t = 51 ps, TOF1 σ_t = 62 ps
  - TOF0-TOF1: pion-muon separation
  - TOF1-TOF2: electron rejection



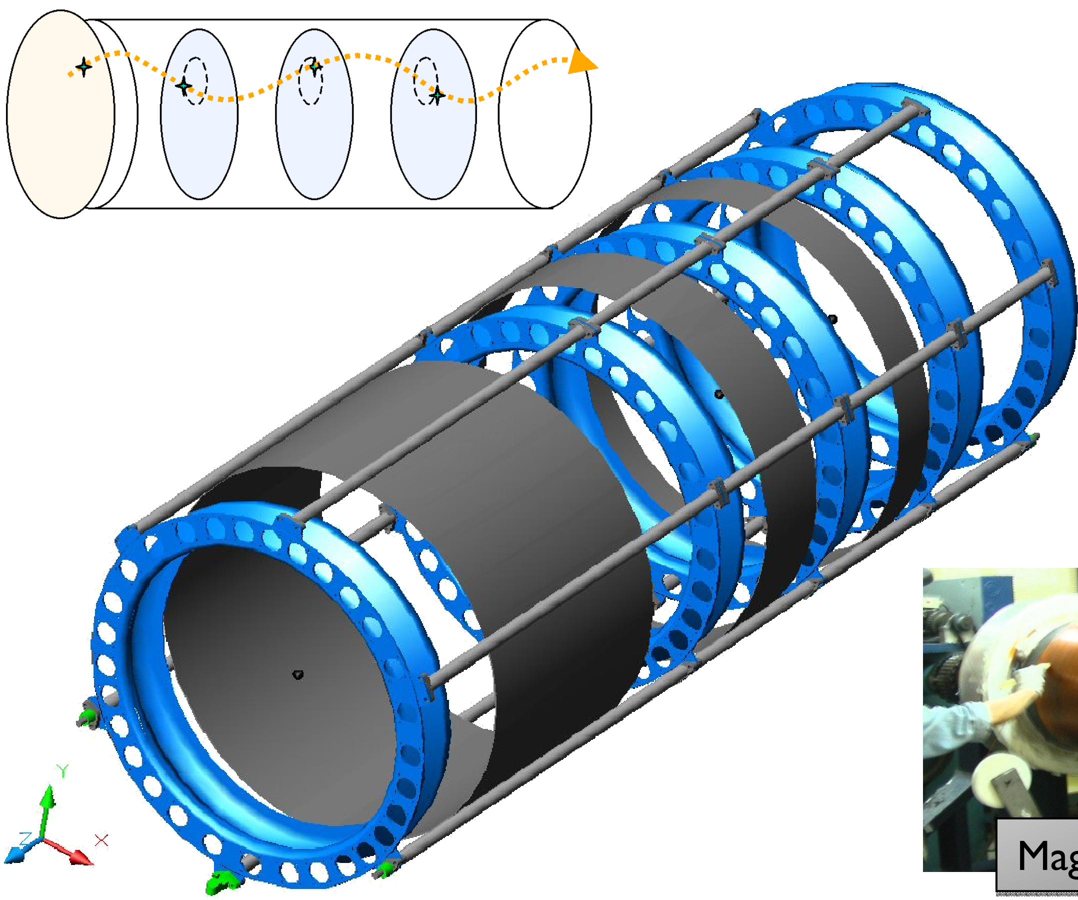


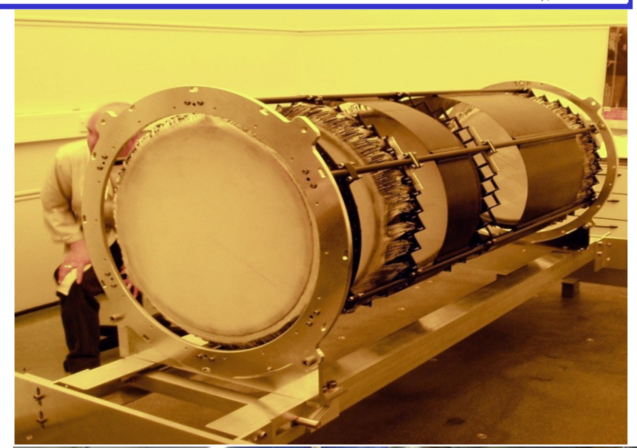


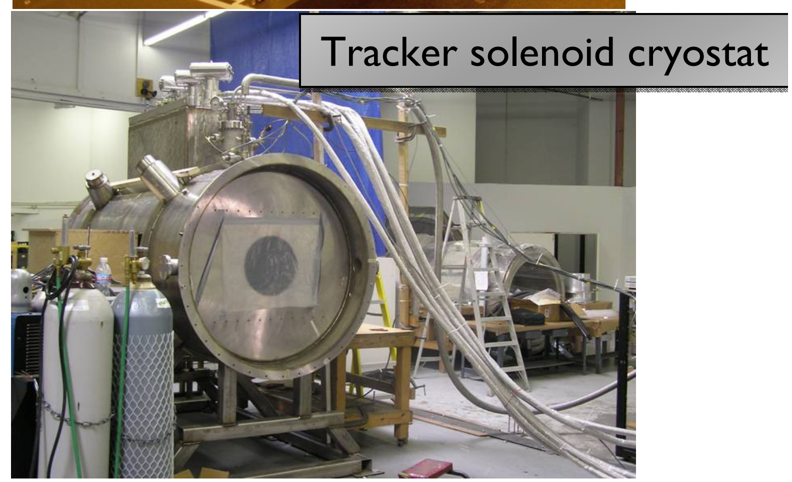


MICE Detector systems

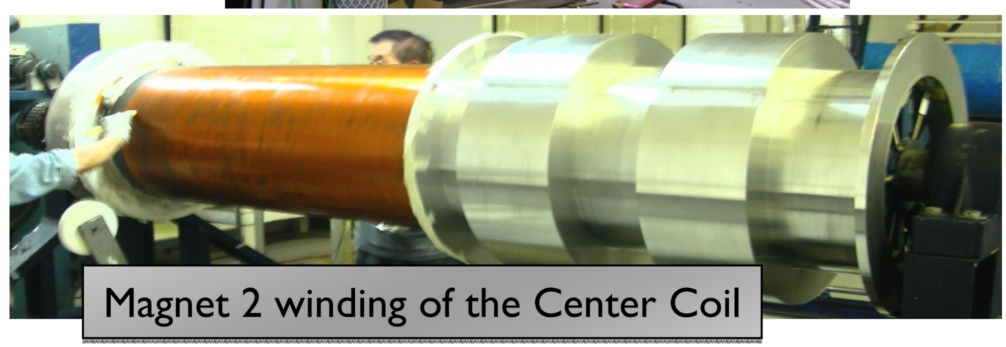
- Scintillating fibre tracker:
  - Two trackers in 4T solenoid, with 5 SciFi tracking stations in each tracker
  - Resolution: 0.4 mm spatial, 1.1 MeV/c p_t and 3.9 MeV/c p_z







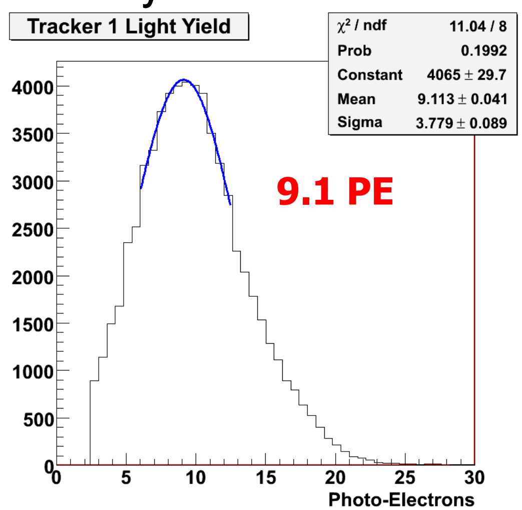
Tracker solenoid cryostat

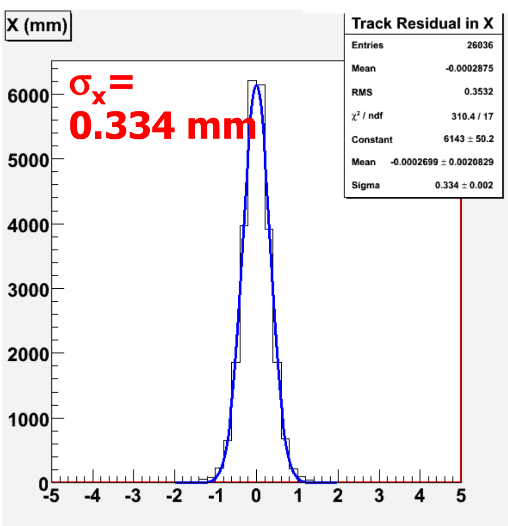


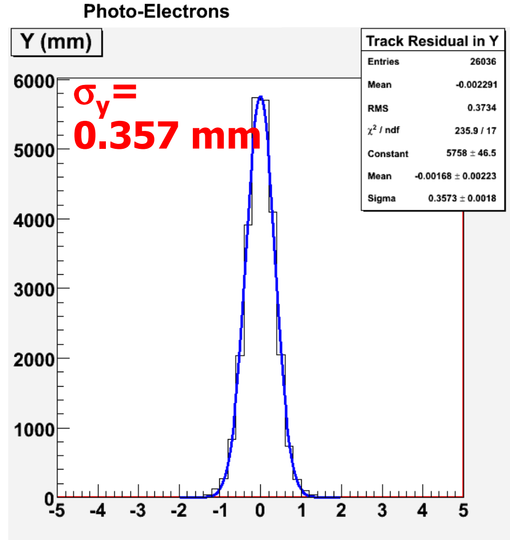
Magnet 2 winding of the Center Coil

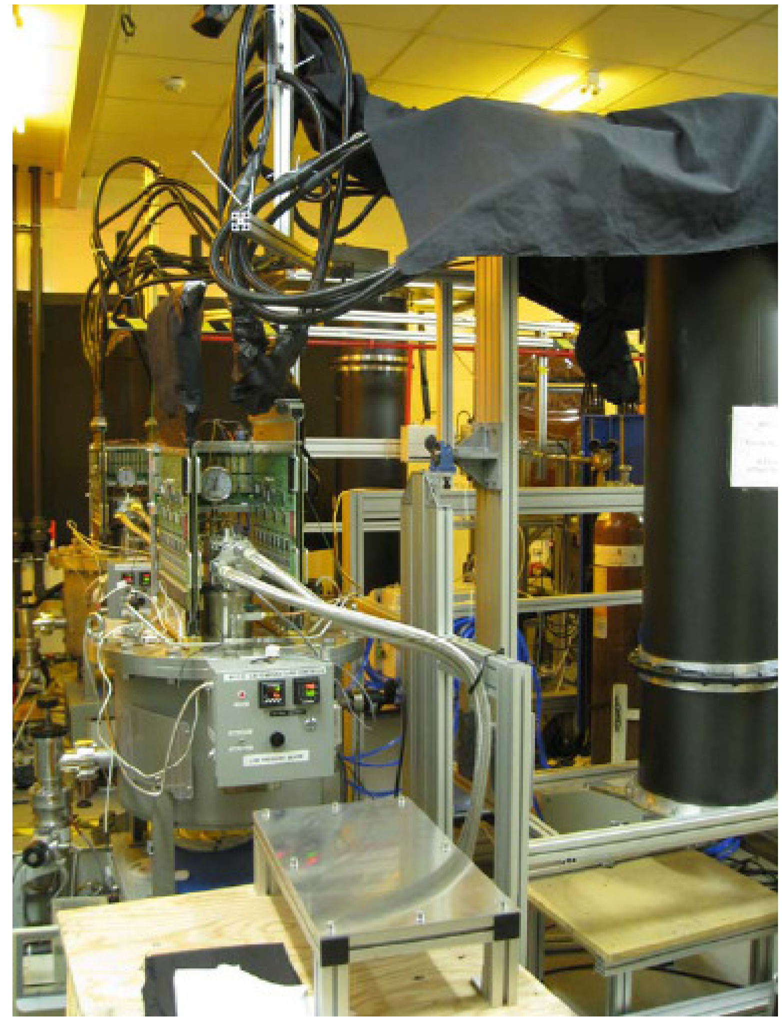
MICE Detector systems

- Calibration scintillating fibre tracker with cosmics:
  - Hit efficiencies per station: 99.38% - 99.86% (only 3 dead channels)
  - Photoelectron yield: 9.1 PE



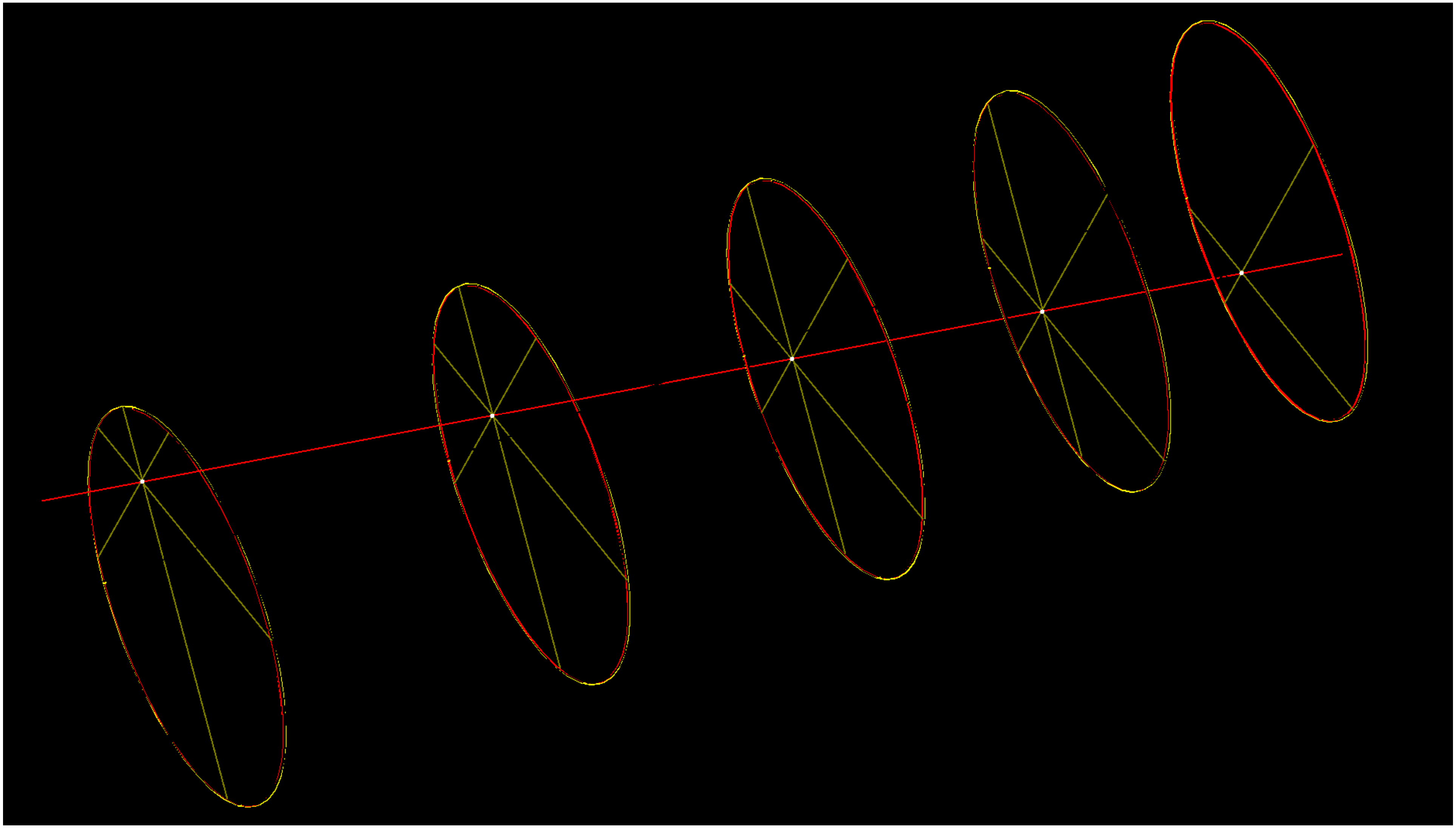






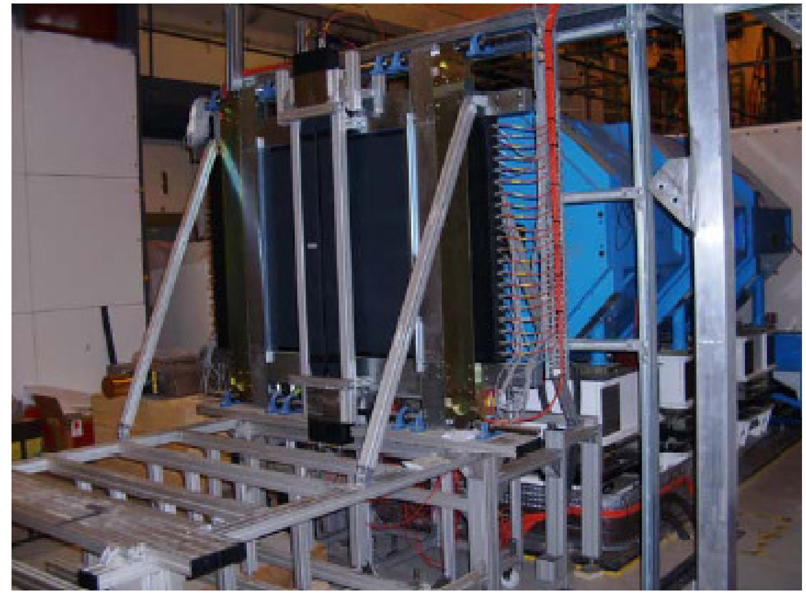
MICE Detector systems

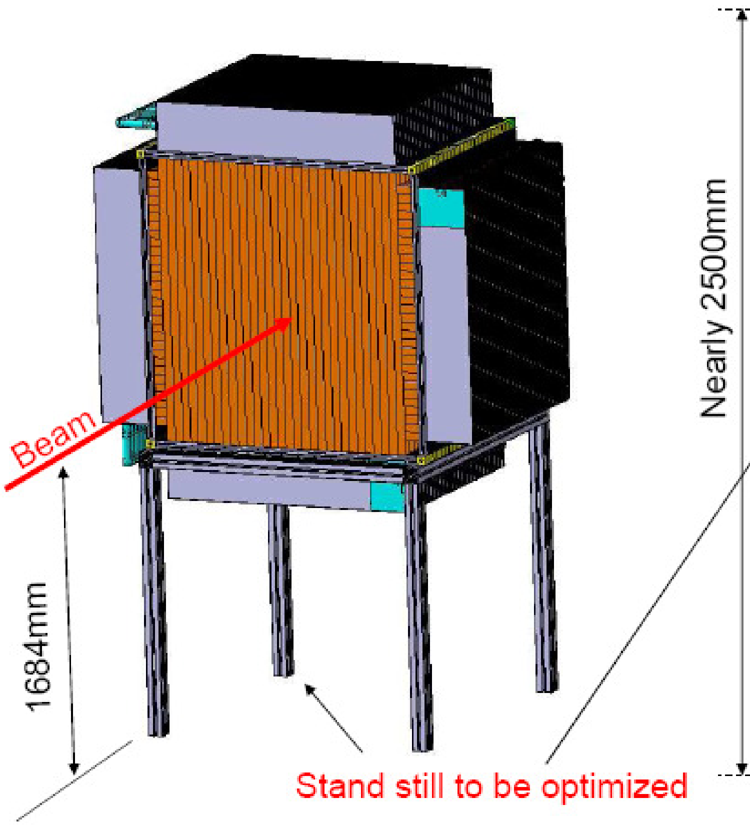
- Tracker event display:



MICE Detector systems

- MICE Electron-Muon-Calorimeter:
  - Dedicated to electron-muon separation.
  - KLOE-Like (KL) lead-scintillating fibre calorimeter: 4 cm preshower grooved lead foils with scintillating fibers, (installed and tested at RAL)

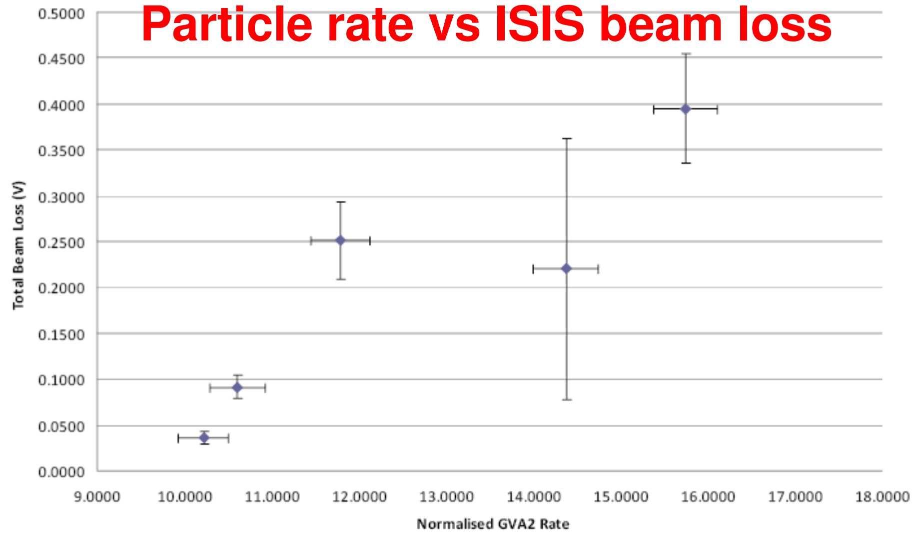




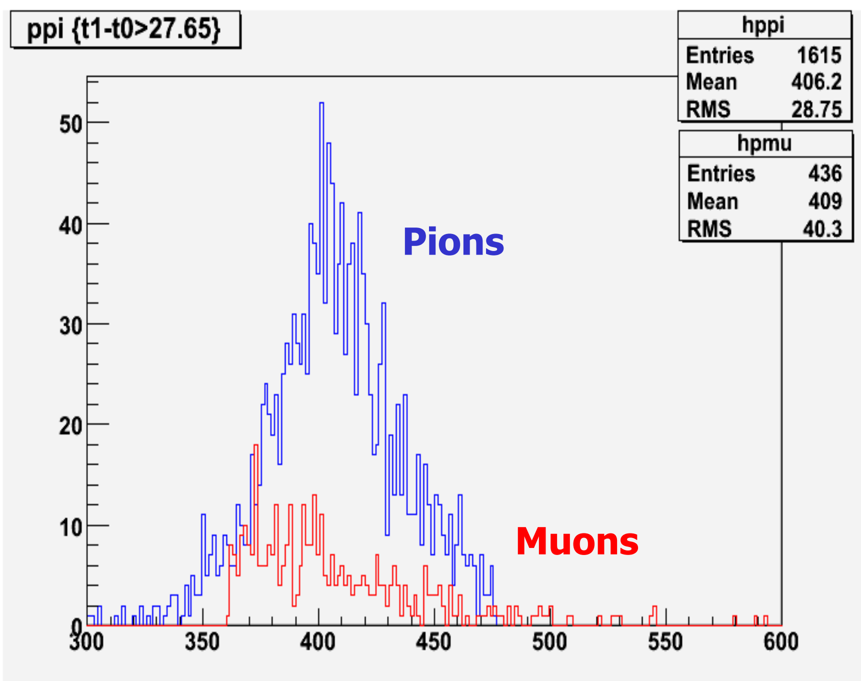
  - Electron Muon ranger (EMR): 25 modules (150 cm) of triangular plastic extruded scintillators to measure energy and range

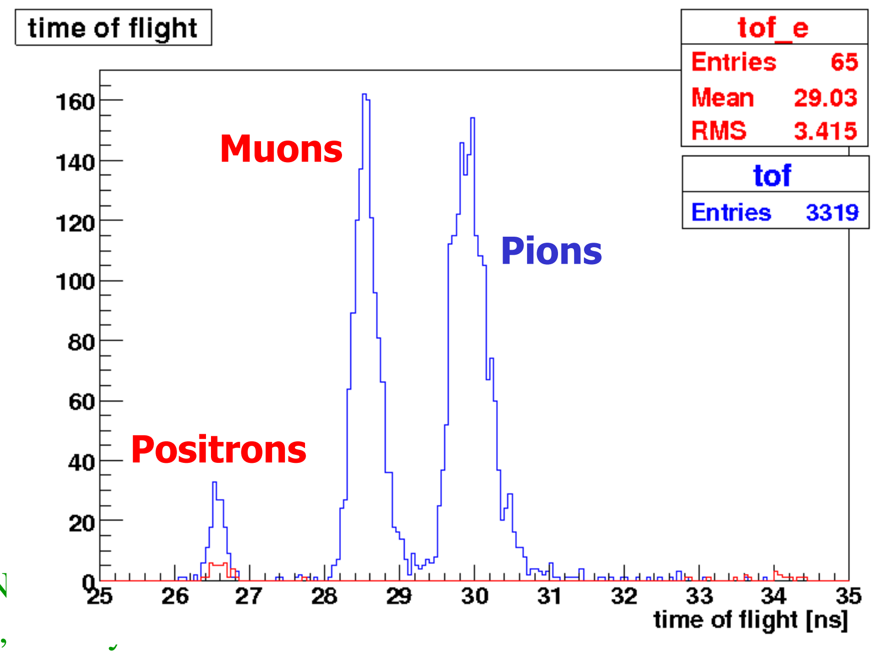
MICE Commissioning

- First MICE commissioning run: Mar-Dec 08
  - Successfully ran beamline (without solenoid)
  - Observed rates in beam counters versus ISIS beam loss



Particle ID with TOF/CKOV: $\pi/\mu/e^+$

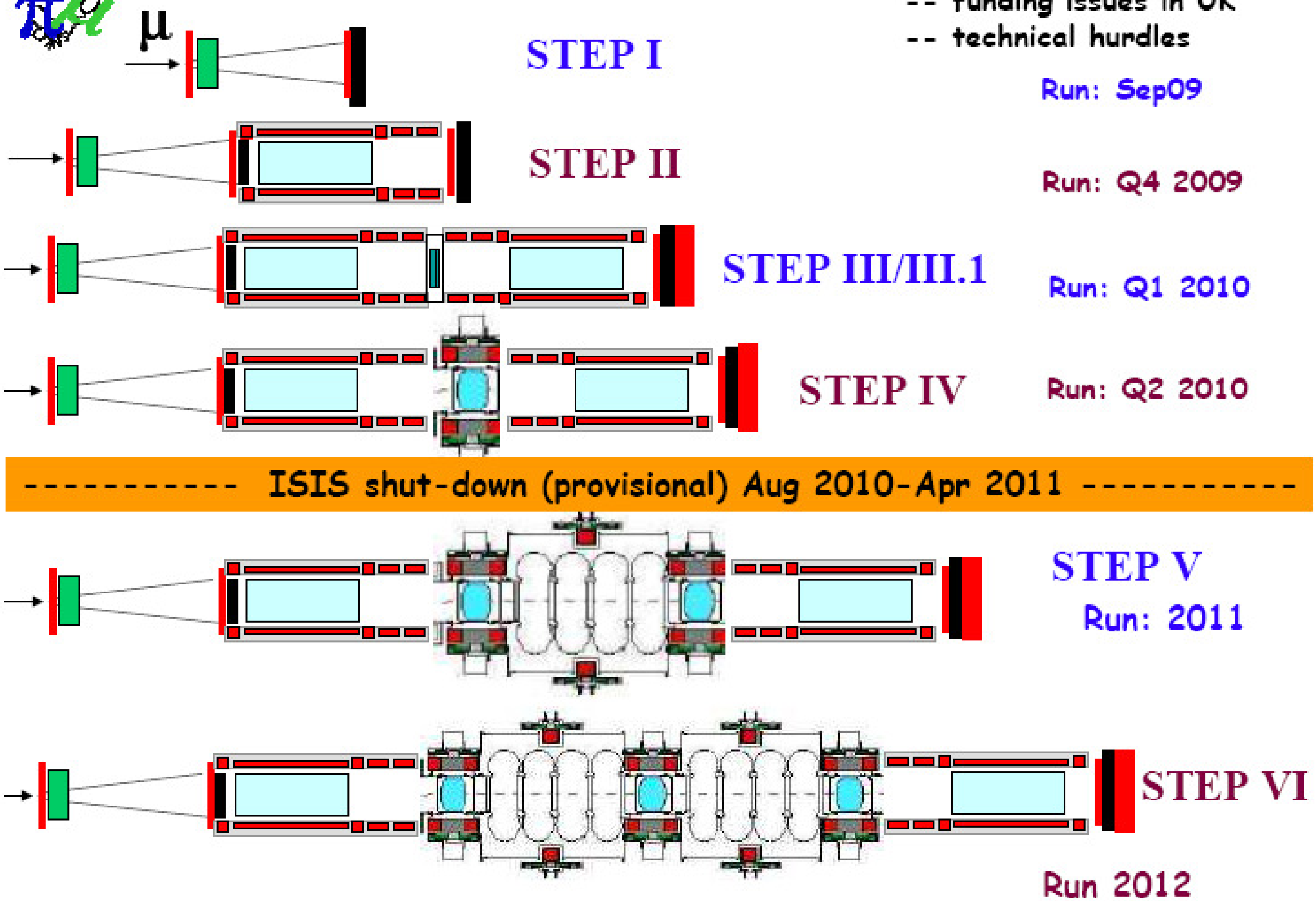




MICE Schedule

MICE Schedule as of April 2009

Caveats: -- cost and schedule review
-- funding issues in UK
-- technical hurdles



Conclusions

- Commissioning MICE beam commenced 2008!
- MICE target operated from Mar-Dec 2008.
- Particles observed using TOF/CKOV counters.
- New target, decay solenoid and tracker to be ready in September 2009 ==> MICE Steps I & II (emittance measurement)
- Steps III/III.1 & IV should occur in 2010.
- Step VI expected 2012.

On track for observation of ionization cooling by 2012!